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Risø National Laboratory, Roskilde, Denmark
June 1999

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Differences in Methodologies used for Externality Assessment

Why are the Number Different?

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June 1999

Abstract The production of energy gives rise to different kinds of damage to the environment depending on the specific type of technology used in producing a given energy supply. The common term that expresses the costs of these environmental damages is externalities. These are costs that are not included in the cost and price structure faced by the producer and the consumer.

During the last few years, externalities related to power production technologies have been calculated making use of different methodologies. The external costs may turn out to be very different for the same fuel cycle depending on the methodology that has been used to assess the externalities.

The report gives a review of different valuation issues, which are used in different externality studies and focuses on why the numbers often are different for the same fuel cycle, using different methodologies for assessment of the externalities. The review of externality valuation focuses in this report on the assessment of environmental externalities. Importance has been attached to health effects, as these are the dominating effects in the external costs. Other effects are only mentioned on a superior level.

The report points out different parameters, which are important to consider when externalities estimated for the same fuel cycle in different studies are compared. For instance some studies transfer dose-response functions and monetisation values from other studies. It is in this case important to consider for each of the functions if it is possible to use functions from other studies, or if it is necessary to develop a function for a new region.

An important parameter in estimating externalities based on earlier studies is the fact that some studies only include regional and local impacts and do not take the global impacts related to greenhouse gasses into account. Considerable uncertainty is related to the global externalities regarding time horizon for the greenhouse effect, choice of dose-response function and monetisation values. Assumptions on famine and the monetisation of human life may be the totally dominating factor estimating external costs.

8 studies have been chosen for further analysis and comparison in order to show the variation in external costs. The studies have been chosen in order to cover as well old, well-known studies as new, less known, but interesting studies. Some of the new studies are based on results from earlier studies, while others implement new ideas concerning the methodology.

The comparison shows the importance of possessing knowledge of which kind of methodologies have been used, which impacts are included etc. to explain why the numbers vary so much in different studies for the same fuel cycle.

As an example a comparison of the impacts and damage costs related to air emissions has been made for three studies using different methodologies. The external costs are estimated for the same reference plant using the dispersion models, dose-response functions, impacts and monetary values from the three studies. The estimates from the three studies are compared two and two, and a more detailed analysis is performed in relation to human health, which is the dominating impact in all externality studies.

When the results are compared, it becomes clear that the impacts included in the studies as well as the monetary values and the dose-response functions used in the models to calculate the impacts are quite important. However, another important issue is the location of the plant, as differences in population size and differences in background levels of the emissions are quite important parameters, when utilising dispersion models for externality estimations.

It is therefore quite important when politicians use externalities to assess the importance of different kinds of energy technologies, and also when externalities are used by the electricity utilities to choose between different technologies in capacity building, that they use external costs for the technologies based on the same approach calculating the same impacts and using same monetary values and dose-response functions.

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Contents

Preface

The report documents the work carried out in the project "Analysis of methodological differences in the assessment of environmental externalities related to energy production". The purpose of the report has been to give an overview of different methodologies used for externality assessment and to analyse selected studies in order to indicate differences in the externalities estimated in the studies.

The report is based on a collection of different working papers through the project. The project has been finalised with this report and an international article comparing two international studies.

During the project Wolfram Krewitt from IER, Stuttgart University, Germany, has contributed to the study with valuable information and discussion concerning the european EcoSense model. Concerning the american EXMOD model the estimations have been discussed with Stephen S. Bernow and William W. Dougherty from Tellus Institute in Boston, USA, who have been helpful with information regarding the model. In relation to the Northern States Power Company Study the estimations have been discussed with Reed Johnson and Spencer Banzhaf from Triangle Economic Research. Both have been helpful in the discussion of the methodology used for comparison and have contributed with additionel model data.

A smaller group of people has followed the project. The group has commented the studies chosen for comparison and has reviewed the international article made during the project. The group has consisted of the following people, who all have been involved in work on externalities:

Bent Sørensen, Roskilde University, DK
Per S. Nielsen, Technical University of Denmark, DK
Søren Varming, Elsamprojekt (the Danish Utilities), DK
Rosa Saez, Ciemat, Spain
Kees Dorland, IVM, Holland

The study has been partly financed by the Danish Energy Agency, Copenhagen, Denmark, journal no. 1753/97-0011. The work has primarily been carried out by senior scientist Lotte Schleisner. Senior research specialist Poul Erik Morthorst has been involved in the assessment of the Northern States Power Company Study.

1 Introduction

Choosing one energy option or another may influence many aspects of society and the environment, which should be accounted for if we want to obtain the highest benefits for the society. These impacts on society or environment, which are not accounted for, are termed externalities. Externalities related to energy production are in general defined as costs imposed on society that are not accounted for by the producers or consumers of energy, in other words damages not reflected in the market price. Normally, thinking of externalities related to energy, the externalities are environmental. An often-cited example is the loss of production in fisheries due to the spill of pollutants in rivers caused by energy use. Public health, agriculture and ecosystems, are other examples of parameters affected by the use of energy by others. The effects may be positive (external benefits) or negative (external costs) and their consideration may make some energy options more attractive than others in spite of their higher costs or vice versa.

In this report the review of externality valuation will focus on the assessment of environmental externalities, and less attention will be paid to the non-environmental externalities.

Over the last decade, several attempts have been made to quantify, and express in monetary terms, the externalities of different energy sources. Externalities may be assessed using different methodologies. Some studies use a "top-down" or macro approach, while others are based on a "bottom-up" or micro approach. Some studies are based on a life cycle assessment, including all impacts from extraction of materials for manufacturing to disposal, while some studies only assess impacts related to the fuel cycle. Especially in the case of renewable energy technologies this will cause a difference in the external costs. Differences in methodologies may also be noticed in the quantification and valuation procedure. Some studies rely on previous estimates, which are not site-specific; other studies rely on abatement costs, being the marginal costs of abating emissions. Other studies use the damage function approach, where the impact from each burden related to the technology is identified, and the damage caused by the burden is quantified and monetised.

An important parameter in estimating externalities based on earlier studies is the fact that some studies only include regional and local impacts and do not take the global impacts related to greenhouse gasses into account. Considerable uncertainty is related to the global externalities regarding time horizon for the greenhouse effect, choice of dose-response function and monetisation values. Assumptions on famine and the monetisation of human life may be the totally dominating factor estimating external costs.

In the following paragraph some of the most important reasons for differences in the numbers are mentioned.

2 Major valuation issues

2.1 Top-down versus bottom-up approach

The "top-down" approach was undertaken by Hohmeyer (1988), and followed by Ottinger et al (1991). It calculates externalities in an aggregated way, typically at a regional or national level. The steps followed by this methodology are the following: first, estimates of total damages from a certain impact are identified from other studies. Then, the fraction of the total impact attributable to a fossil fuel is calculated, to estimate the contribution of this fossil fuel to the total damage. This methodology is useful, because of its relative simplicity, to get a broad view of the damages caused by fuel cycles. However, several drawbacks may be identified. First, this method relies heavily on approximations and previous estimates of total damages. It does not take account of the different fuel cycle stages, and effects due to variations in burdens and receptor distribution are neglected. Therefore, site-specific effects can not be assessed, nor can the effects of additional or marginal impacts be estimated.

Site-specific estimates may be provided by a "bottom-up" approach. The study by Pace (1990) estimated emissions, their dispersal, the population and environment exposed, and the impacts and costs produced. All these estimations came from numerical values from previous studies. The same approach was followed by Pearce et al (1992), who addressed more impacts than Pace. In none of the cases were data collected at the primary level, so they cannot be considered site-specific, as they do not take account of site differences.

The latest approach to externality assessment is that proposed by the ExternE project of the European Commission (1995). This is a bottom-up methodology, which tries to eliminate the problems of other methods. The ExternE methodology is based on a damage function approach, being a series of logical steps tracing the impact from the activity that creates it to the damage it produces, independently for each impact and activity considered. This allows for a marginal, site-specific assessment.

Top-down studies identify average costs, whereas site-specific bottom-up analyses identify the costs associated with marginal impacts. At a policy level top-down analyses are useful, because policies mostly address average costs. On the other hand, for environmental costing purposes the bottom-up analyses are useful whenever possible, because it is the environmental cost of a new proposed resource that must be selected based on marginal costs. However, generic estimates of environmental costs based on top-down analyses are often the only estimates available. Therefore, in the absence of site-specific estimates the generic estimates must be used.

2.2 Damage costs versus control costs

Environmental costs may be estimated either by using damage costs or control costs. Damage costs are the costs of damages inflicted on society by pollutants, while control costs are the costs of controlling or mitigating pollution damages.

The damage costs are the most relevant costs to be used in the assessment of external costs, as it is the damages to the society that are sought to be addressed by incorporating environmental external costs when choosing utility resources. The problem in using damage costs is the difficulty in calculating them.

If damage cost studies are insufficient, for instance in the case of global warming, control costs can serve as a proxy. Control costs are easier to estimate, because data on the costs of control is more readily available. Control costs, however, have no or only minor relationship to the cost of the damages imposed on society by the relevant pollutants.

2.3 Methodology

Earlier studies are mostly literature reviews that take estimates of pollutant emissions and impacts from other studies and then multiply these estimates by economic values. Newer studies use mostly some kind of variation of the damage function approach. This methodology estimates externalities by identifying general pathways for each source of the damage from a LCA point of view. Dispersion models are used to estimate the concentration of the emissions and dose-response functions are used to calculate the resulting health effects and ecological impacts. Different valuation functions are used to calculate the economic damages of the impacts. In some cases computer models have been developed including dispersion models, dose-response functions and monetisation values (European Commission, 1995) (Rowe et al., 1995).

In general the emissions, concentrations and impacts used in the literature based studies are greater than the estimates calculated using the damage function approach.

2.4 Atmospheric modelling

The expected concentration of emissions in different areas away from the plant and the distribution of population and environmental receptors in these areas are important parameters in assessing ecological and health impacts from emissions. Therefore modelling the dispersion of emissions is a very important factor in estimating externalities. Many studies, however, stop at estimates of emissions without atmospheric modelling.

Typically two kinds of models exist, one for local scale modelling and one for regional scale modelling. For local scale modelling a model often used is the Gaussian Plume model. The model neglects chemical reactions, but is detailed in the description of turbulent diffusion and vertical mixing. The concentration distribution into the atmosphere is assumed to have a Gaussian shape. The model assumes idealised terrain and meteorological conditions so that the plume travels with the wind in a straight line. Dynamic features, which affect the dispersion, for example vertical wind shear, are ignored, which limits the model to a region within 50 km of the source. The Gaussian plume model is not feasible for regions with complex topography, and better-adapted models should be used if possible.

On a regional scale chemical reactions cannot be neglected. The annual pollution on a regional scale may be assessed by using a model with a simple representation of transport and a sufficiently detailed representation of chemical reactions. An example of this may be the receptor-orientated Lagrangian plume model.

2.5 Dose-response functions

The term 'dose-response' is defined as the response to a given exposure of a pollutant in terms of atmospheric concentration.

Dose-response functions appear in a variety of functional forms. They may be linear or non-linear and contain thresholds (e.g. critical loads) or not. Some of the dose-response functions describing effects of various air pollutants on agriculture have proved to be particularly complex, incorporating both positive and negative effects, because of the potential of certain pollutants, e.g. those containing sulphur and nitrogen, to act as fertilisers.

A major issue with the utilisation of dose-response functions is the assumption that they are transferable from one context to another. For example, some of the functions for health effects of air pollutants are derived from studies in the USA. There may be problems in using these functions for Europe, Thailand or other continents, as there is good reason to suspect that there will be some variation, resulting from the affected population, the exact composition of the pollutants the study group was exposed to, etc.

2.6 Identification of damages

The effects of many impacts are highly dependent on the location and characteristics of the source, the distribution of populations, topography and climate. Therefore, externalities derived in one region or country may not be transferable to another region. Another important parameter in estimating externalities based on earlier studies is the fact that some studies only include regional and local impacts and do not take the global impacts related to greenhouse gases into account.

2.6.1 Local impacts

Local impacts are impacts close to the fuel cycle activity and are typically the result of a burden like noise or visual intrusion in a distance of a few kilometres from a plant. The analysis of local impacts is more straightforward than that for regional or global impacts. Analyses range from the use of statistical data to more elaborate analysis such as the assessment of noise effects. Typically many local impacts are identified, but in practice they are negligible compared to regional and especially global impacts.

2.6.2 Regional impacts

Regional impacts are experienced over long distances affecting a large number of people. Regional impacts are typical impacts related to acid emissions and particulates. Regional impacts are mostly assessed using dispersion models to obtain the regional dispersion. The complexity of the models and data used in regional assessments varies widely.

It may vary which emissions are included in the different studies, and the regional externalities may therefore be much larger in some studies compared to others.

2.6.3 Global impacts

Global impacts are related to CO_2 and other greenhouse gases and the resultant impact is on climate change. Different kinds of control cost approaches may be used to estimate the costs of global warming. Using mitigation costs you predict the environmental impacts of global warming and calculates the cost of enduring or repairing the harm. Another way of using control cost approach is to calculate the costs of reducing the greenhouse gas emissions e.g. by improved energy efficiency. The third approach is to calculate the cost of sequestering the CO_2 emitted to the atmosphere by planting trees or other vegetation that will remove CO_2 from the atmosphere.

There is a number of practical problems in evaluating the possible costs of global warming. The time scale of the effects is very long, which makes it difficult to estimate the extent of human adaptation. In addition, the traditional methods of cost-benefit analysis become very sensitive to the choice of discount rate over such long periods. Considerable uncertainty is related to the global externalities regarding time horizon for the greenhouse effect, choice of dose-response function and monetisation values. Effects of global warming are mostly predicted by use of computer-based analyses. These are able to predict only relatively large-scale weather phenomena such as seasonal temperature changes and broad rainfall patterns.

A number of people has carried out studies of the economic impacts of global warming. None of these have claimed to provide a full valuation of all possible impacts of global warming. Nevertheless, some basis for a methodology has been laid down.

2.7 Economic valuation methods

When damages related to an energy production technology have been identified these need to be monetised. Different methods for economic valuation exist and may be used. The methods mostly applied for economic valuation are accounting methods, revealed preference methods (incl. hedonic pricing) and contingent valuation methods.

2.7.1 Accounting methods

Accounting methods may be used to estimate costs such as medical expenditures, maintenance costs, crop and timber losses with and without the environmental effects. Market prices can often be used directly for pricing the environmental effects. For instance if the effect of a pollutant is reduced yields of a commercial crop, the external cost may be estimated by multiplying the observed market prices of the crop by the reduction in yield caused by the pollutant.

2.7.2 Revealed preference methods (hedonic pricing)

Revealed preference methods are based on observed behaviour, for instance the observed frequency and distance people will travel to enjoy a certain recreation site. The recreation site may be valued by using a demand function that relates the rate of use for visitors to their cost of travelling to the site.

Hedonic price methods use market prices to impute prices to non-market goods and services by comparing the market price of a good, that embodies the non-market service to the price of the same good, that does not embody the non-market service. The difference between the two prices represents the value of the non-market service. For example, you may compare wages of workers exposed to an occupational risk to wages of workers not having that risk. The difference in wage is an estimate of the value of the occupational risk, assuming that all other factors are equal. The problem in hedonic pricing is to insure that all other factors are equal.

2.7.3 Contingent valuation methods

The method referred to as the contingent valuation method is based on survey techniques, where people are asked what their willingness is to pay (WTP) for a reduction in the pollutant or their willingness to accept (WTA) for an increase in the pollutant. The resulting values do not depend on the actual behaviour or market prices.

Contingent valuation is useful to estimation of the value of non-market goods and services. For instance WTP may be used to estimate the price of noise from a wind turbine.

2.8 Valuation of health risk

One of the most important parameters when estimating externalities is the valuation of human health risks. This parameter is the most significant and also the most controversial parameter in the assessment of external costs. The value of human health risks is estimated by the value of the risks to life. This may be valued either by society's willingness to avoid the risk or the willingness to be compensated to suffer this risk.

Health risk values are often expressed as the value of a human life. Aggregating the value to a single life makes comparison possible and therefore the expression "the value of a statistical life" (VSL) is used in many externality studies. VSL is calculated by estimating the willingness to pay (WTP) for a reduction in the risk of death. Though it has nothing to do with avoiding certain death. Estimates of WTP for a reduction in risk or the willingness to accept (WTA) of an increase in risk may be made by three different methods 1) wage risk, 2) contingent valuation, 3) consumer market surveys.

Using the wage risk method the increased compensation people need, other things being equal, to work in occupations where the risk of death at work is higher, is estimated. The contingent valuation method is based on surveys on peoples WTP and WTA for measures that reduce the risk of death from certain activities (e.g. driving) or their WTA for measures that increase it (e.g. increased road traffic in a given area). The third method is based on actual voluntary expenditures on items that reduce the risk of death from certain activities (e.g. stopping cigarette smoking or purchasing air bags for cars).

2.9 Discount rates

Discount rates are used to compare future economic costs with today's costs. Low discount rates weigh the future more heavily than high discount rates. The discount rate used in a study is therefore an important factor when comparing results from different studies.

There are several views on how discount rates should be used to value environmental resources. Some economists and utility experts argue for using rates similar to those used by utilities for valuing capital investments (e.g. 6 to 8 percent). This provides a consistent basis for utility resource selection decisions, but it also has the effect of reducing the value of damages that occur in the far future (e.g. global warming or nuclear waste storage) to nearly zero.

Low discount rates have the advantage of treating future generations equally to our own, but they also may cause relatively certain, near-term effects to be ignored in favour of more uncertain, long-term effects. Future generations may have new technologies and knowledge that will cheaply and easily deal with long-term environmental threats such as global warming. In other studies a discount rate of zero has been used for moral reasons, particularly in the respect to human life and health risks.

The output of the global warming analysis is very sensitive to the discount rate, which is used to value future costs. This is because the impacts of global warming happen in the future, and are discounted by whatever rate is used, while the costs of mitigation occur in the present.

3 Differences in methodologies used for externality assessment

When comparing externalities for different fuel cycles it is important to use the same methodology for all fuel cycles, as it allows for a consistent comparison between the fuel cycles. Although uncertainty cannot be removed, at least some of it may be eliminated when the different fuel cycles are compared, as the estimation method is the same, and thus differences will be due only to each fuel cycle.

The following 8 studies have been chosen for further analysis and comparison.

- ExternE National Implementation
- IEA Greenhouse gas R&D Programme "Full Fuel Cycle"
- The New York Electricity Externality Study
- The Northern States Power Company Study
- US-EC fuel cycle study
- Environmental costs of coal-based thermal power generation in India
- External costs in the Swiss Energy Sector
- Social costs of Energy Consumption

The studies have been chosen in order to cover as well old, well-known studies as new, unknown, but interesting studies. Some of the new studies are based on results from earlier studies, while others implement new ideas concerning the methodology. Most of the chosen studies are bottom-up studies using "The damage function approach". However, in the Northern States Power Company Study the external costs are estimated for scenarios instead of for one single plant, and the external costs estimated in this study is therefore not direcly comparable with the other studies. Therefore the study has not been included in Table 3.1, which shows the results from the other studies, translated to mECU/kWh year 1995.

Table 3.1 External costs in mECU/kWh year 1995 for different fuel cycles for the studies chosen (1.2US$(1992) = 1 ECU (1995))

	Coal /Oil	Natural gas	Nuclear	Wind	Biomass
ExternE (Schleisner and Nielsen, 1997)		NGCC: 7.1-80		Off-shore: 0.7-3.6 On land: 0.6-2.6	Biogas: 4.4-16.1
IEA (ETSU, 1994)	PC: -0.6-5.4	NGCC: 0.6-2.3 IGCC: 1.6-3.9			
New York (Rowe et al., 1995)	PC: 4.5 FB: 0.9	NGCC: 0.2			Wood: 3.5
US-EC (Oak Ridge, 1992)	Coal: 0.4-1.0 Oil: 0.1-0.2	0.01-0.2	0.1-0.2		Wood: 1.6
India (Bhattacharyva, 1997)	Coal: 9.4				
Swiss (Ott, 1997)	Oil:99.6-158	NGCC: 68-101	4.8-11.5		
Social costs (Hohmeyer, 1988)	Fossil fuels: 7.4-40	Fossil fuels: 7.4-40	7.8-78.3	On land:0.1	

PC: pulverised coal , FB: fluidised bed coal, NGCC: natural gas combined cycle, IGCC: Integrated gasification combined cycle

The results from the US-EC study are very low. One reason for this is that the global warming effect is not included in the results. The results from the Swiss study are rather high compared with results from the other studies. The results for natural gas in the ExternE study are high compared to the other studies. The reason for this is that external costs related to CO_2 are included in this study, while CO_2 is not included in the New York study, and in the IEA study CO_2 is captured.

The above comparison shows the importance of knowledge of which kind of methodologies have been used, which impacts are included etc. to explain why the numbers vary so much in different studies for the same fuel cycle. One thing evident is that the impacts, damages and externalities are very project specific. For example emissions expected from an integrated gasification combined cycle coal plant are considerably lower than from a pulverised fuel plant. The specifications of the plant to analyse will in this way affect the magnitude of the externalities. The specifications include as well installed pollution abatement technologies and their efficiencies as stack height and other source parameters that are used in atmospheric transport modelling. These parameters may be problematic to define for future technologies.

4 Overview of selected studies

The following overview gives a description of the selected studies in regard to which methodology has been used, the impacts included, valuation methods etc. The overview may give an estimate on why the external costs found in the different studies vary so much.

4.1 ExternE National Implementation

The objective of the ExternE National Implementation project (EC 1995), (Schleisner and Nielsen, 1997) has been to establish a comprehensive and comparable set of data on externalities of power generation for all EU member states and Norway. The tasks include the application of the ExternE methodology to the most important fuel cycles for each country.

The methodology used for assessment of externalities of the fuel cycles selected is a "bottom-up" methodology with a site-specific approach; i.e. it considers the effect of an additional fuel cycle, located in a specific place. The study estimates the damage costs related to different fuel cycles.

Quantification of impacts is achieved through the damage function approach. The study is using a unified approach to ensure compatibility between results. This is being achieved through the use of the EcoSense software package, which assesses the environmental impacts and resulting external costs from electricity generation systems. The system has an environment database at both a local and regional level including population, crops, building materials and forests. The system also incorporates two air transport models, allowing local and regional scale modelling. The model used for local modelling is a Gaussian plume model, while the model used for regional scaling is a receptor-orientated Lagrangian model. A set of impact assessment modules, based on linear dose-response relationships, and also a database of monetary values are included for different impacts. There is no model for ozone included in the software, but ozone is estimated as a simple relationship to NO_x.

As well local, regional as global impacts are assessed. The monetisation values used for CO_2 have been estimated using two different models. Four different values have been used: 3.8 ECU/t CO_2, 18 ECU/t, 46 ECU/t and 139 ECU/t CO_2. The estimate in Table 1 is based on a CO_2 value of 18 ECU/t.

The underlying principle for the economic valuation is to obtain the willingness to pay of the affected individuals to avoid a negative impact, or the willingness to accept the impact. A limited number of goods of interest to this study - crops, timber, building materials, etc. - are directly marketed, and for these valuation data are easy to obtain. However, many of the more important goods of concern are not directly marketed, including human health, ecological systems and non-timber benefits of forests. Alternative techniques have been developed for valuation of such goods, the main ones being hedonic pricing, travel cost methods and contingent valuation.

The central discount rate used for the study is 3%, with upper and lower rates of 0% and 10% also used to show sensitivity to the discount rate. For the valuation of health risk a value of 3.1 MECU has been used for the value of a statistical life. This value has been used for valuing fatal accidents, mortality impacts in climate change modelling and similar cases where the impact is sudden and where the affected population is similar to the general population for which the VSL applies. In the case of deaths arising from illness caused by air pollution the YOLL (years of life lost) approach has been used. YOLL depends on a number of factors such as how long it takes for the exposure to result in illness and the survival time for the individuals.

The base year for the valuation is 1995, and all values are referring to that year. The study is from 1997. A wide range of technologies has been analysed, covering more than 60 cases for 15 countries and 11 fuel cycles including fossil fuels, nuclear and renewables.

4.2 IEA Greenhouse gas R&D Programme "Full Fuel Cycle"

This study (ETSU, 1994) is based on a "bottom-up" approach assessing the damage costs related to the full fuel cycles of three types of power plants: Natural Gas Combined Cycle (NGCC), Integrated Gasification Combined Cycle (IGCC) and Pulverised Fuel (PF). The study is from 1994.

The power generation plants are combined with three options for abatement of CO_2 emissions: Disposal of CO_2 to disused gas wells, disposal of CO_2 to the deep ocean and sequestration of CO_2 to a sustainable forest. 2005 has been selected as the base year, being the earliest date for CO_2 abatement technologies to be available. The technologies assessed are as advanced as possible.

The study is based on the first ExternE study (CEC, 1995a-f), and the methodology used in the project is the damage function approach. The study is based on a LCA including all stages of the fuel cycle from extraction of fuel to waste disposal and electricity transmission as far as the national grid. The ExternE methodology has been improved in the study especially concerning the greenhouse gas effect.

The dose-response functions used in the study are derived from the results of several other studies, especially the ExternE study. The used functions are linear relationships. Concerning global warming the study follows the IPCC impact methodology. A computer model has been used to estimate climate changes caused by greenhouse gases. The period for implications of greenhouse gases has been restricted to 100 years.

Two models have been used to describe the transport and chemistry of atmospheric pollutants. Gaussian plume models have not been used, because these models are for short ranges about 50 km, while the actual cases have larger ranges.

Economic valuation is in some cases based on market prices, in other cases prices are based on published studies using contingent valuation, hedonic pricing, travel costs methods or other related techniques. The study uses a discount rate of 1.5 % for environmental externalities.

The valuation of health risk is based on statistical risk and not on the willingness for the individual to pay to avoid a certain death. A value of 3 million $ has been used for VSL, which is within the range conventionally used in USA or UK based studies.

CO_2 has not been valued, as it is assumed that the CO_2 is disposed into the ocean or sequestered. However, these options have not been monetised.

4.3 The New York Electricity Externality Study

In this study (Rowe et al, 1995) the EXMOD model is used, developed at the Tellus Institute in Boston. The model is similar to the European EcoSense model. The EXMOD model is an American model, that models air dispersion from locations in New York to receptor cells throughout the north-eastern U.S. and eastern Canada. The study is from 1995.

The study is a bottom-up study based upon "The damage function approach". In the study damage costs are estimated for 23 new electric resource options within coal, oil, natural gas, nuclear, municipal solid waste, hydroelectric, biomass, wind, solar and demand side management. Default air emission rates, land use and other characteristics are specified for each facility in the model, but these characteristics may be replaced. The air dispersion models in EXMOD are annual average or simple peak models used by U.S. regulatory agencies. The two models are used to predict short-range changes (<50 km) and long-range changes (50-1500 km) covering local and regional range. Also ozone models are included driven by changes in NO_x concentrations. So far the model does not compute CO_2 damages (i.e. EXMOD implicitly assumes 0$/ton CO_2). However, it is possible to include other values for CO_2.

Impact calculations are based on dose-response parameters in EXMOD with default high, central and low parameter values. Based on a review of the literature EXMOD uses a central VSL estimate of 4.0 million $ for individuals under 65 years, and a central estimate of 3.0 million $ for individuals of 65 years or older. The argument for that VSL decreases with age is that years of expected remaining life decrease with age. Thus life expectancy and health status tend to decrease with age so that the quality of life is reduced.

The study uses control cost valuation to estimate the environmental cost associated with various air emissions. For other impacts the study uses the contingent valuation method.

4.4 The Northern States Power Company Study

This study concentrates on assessing the environmental externality costs for electricity generation in the North State Power Company in the U.S., and it is carried out by Triangle Economic Research. The project was finalised in 1995.

Methodologically the study differs from other studies as the external costs are calculated for scenarios consisting of different energy production plants, and not as in most other studies, i.e. the ExternE study, for a single plant. Still the study is based upon "The damage function approach" as in the ExternE study, but no integrated model is used, although the ISCST2-model is used for air dispersion.

The study is looking at impacts to air only, and only connected to the production of electricity by coal- or gas-fired power plants. The study includes 6 pollutants in total: PM_{10}, CO, NO_x, SO_2, Pb and Ozone. Additionally, CO_2 and Hg were examined, but were excluded from the analysis due to lack of data and methodological uncertainties.

Geographically, the study was restricted to the area of NSP, that is Minnesota, western Wisconsin and south-eastern South Dakota, although dispersion is calculated for a larger area.

The externalities from electricity generation in this area is investigated within the context of four planning scenarios:

- Baseline scenario: Existing generation plus the addition of several gas-fired turbines;
- Rural scenario: Addition of 400 MW coal-fired plant plus four 152 MW gas-fired combined-cycle plants in Minnesota; located in agricultural area
- Metropolitan Fringe scenario: Addition of the same plants (400 MW coal plus four 152 MW gas) but located west of Minneapolis/St. Paul close to metropolitan areas
- Urban scenario: Increase of emissions of two coal plants in the Twin cities area.

The three last-mentioned scenarios are developed from and compared to the first-mentioned baseline scenario.

The study uses a relationship between health-state indexes and Willingness to pay (WTP) to avoid different health effects. A health-state index offers an operational framework for classifying individuals according to the level of mobility, physical activity, social activity and most severe symptom or problem complex they may experience. These indexes are based on the idea that health is defined by both objective and subjective components of well being.

A meta analysis has been performed in the study using a number of studies giving WTP for a number of different health effects. These values are then used for any short-term health effect for which it is possible to assign a health state index score. Thus it is possible to establish WTP for an entire range of short-term health effects.

4.5 US-EC fuel cycle study

This study (Oak Ridge, 1992) is the American part of the ExternE study using "The damage function approach". The study is based on a bottom-up approach estimating the marginal consequences of a fuel. The fuel cycles included in the study are coal, biomass, oil, natural gas, hydro and nuclear.

Atmospheric transport models are used to estimate concentrations of pollutants in the air. Gaussian plume models are used for primary pollutants such as particulates, NO_2, SO_2 and air toxics. The study focuses on local and regional damages. Dose-response functions are based on empirical relationships derived through statistical analysis of measured data.

The economic valuation is primarily based on individuals' WTP. The value of things like recreational resources is based on other studies, which account for travel expenses and time to travel to the site. In other situations contingent valuation is used to estimate WTP to avoid undesirable outcomes in hypothetical situations. Ozone and global warming damages have not been monetised in the study.

A major disadvantage of the used methodology has been that data- and computationally it is very intensive. This limitation has been modified in the ExternE National Implementation study with the development of the EcoSense model. The study was finished in 1992. A discount rate of 3 % has been used for the base case in the study.

4.6 Environmental costs of coal-based thermal power generation in India

In this study (Bhattacharyva, 1997) an attempt has been made to estimate the environmental costs of coal-based thermal power generation in India. The study is based on a bottom-up approach. The analysis is principally concerned with the power generation phase from a coal-fired plant, though the environmental costs of coal production have been covered to a lesser extent. The methodology used to evaluate the impacts of pollution from power generation is the damage function approach, while estimates of the environmental costs of coal production are based on control costs. The external costs mentioned in Table 1 only covers the costs related to power production.

A Gaussian model has been used for the analysis of dispersion of pollutants. The damage functions used in the study are based on existing survey data from an industrial area of Bombay. The damage functions used are linear or logarithmic functions. Damages have only been monetised for SO_2 and particulates. Only mortality, morbidity and effects on buildings have been taken into account. Damages due to NO_x have not been estimated monetarily owing to possible double counting problems. CO_2 emissions are not taken into account. The study is from 1994.

Morbidity has been valued by using the price of hospital visits and medicine costs, while effects on buildings have been monetised by using a loss in rent for the buildings. Mortality is valued by using a very low VSL of 287,230 rupees (9044 US$).

4.7 External costs in the Swiss Energy Sector

This study (Ott, 1995) is based upon information from earlier externality studies. The external costs are estimated for the Swiss energy sector as a whole. The analysis is using a top-down approach, estimating the externalities e.g. per ton emission followed by a conversion to price per kWh for different fuels.

The methodology used is "The damage function approach". The external effects are identified based on a LCA of energy processes. For the quantification process available information on physical effects of the identified externalities have been collected and evaluated. Only regional and global damages are identified and monetised. Air pollution, oil spills, health injuries etc. is valued by a damage cost approach. Atmospheric models have not been used, as the impacts are based on results from other studies. Also dose-response functions are based on other studies. For the cost of greenhouse gas emissions an avoidance cost approach has been used by assessing the costs of achieving a CO_2 reduction target by 2025. The avoidance costs based on WTP have been monetised to 160-230 US$/t CO_2. Impairments of natural landscapes by energy infrastructures as well as loss of human life as a result of energy related activities are valued by using willingness to pay data. Other costs have been valued by using market prices. The analysis is from 1994. The prices are based on data from 1990.

Damages to human health have been based on a German study, which has been transferred to Switzerland. Economic valuation is based on the human capital approach, which underestimates real costs (it only includes expenditures in the health sector, salary payments and sickness benefits for employees being unable to work).

4.8 Social costs of Energy Consumption

This study (Hohmeyer, 1988) was the first attempt to assess the external costs related to energy production. Hohmeyers study is a "top-down" study. All fossil fuels are calculated as one case, not including any kind of LCA. As a value for annual emissions the limit values for fossil fuels in Germany are used. Multiplying these emissions with a toxicity factor results in weighed emissions, resulting in a damage factor of 28 % for electricity generation from fossil fuels.

The damages to flora, fauna, mankind, materials and climate change have been calculated using German economic values for forest, materials etc. No dispersion models have been used. The damages are summed up to a total in million DM/a, and then divided by the annual electricity generation. The study is from 1988, but the costs are in 1982 prices.

Its cost estimates are based on several sources. Some estimates come directly from other studies that value specific categories of effects (e.g., human health effects of air pollution). Other estimates involve direct calculations based on damages (e.g., estimating the probability of and health effects from a nuclear accident and multiplying by the monetary value of a life). Finally, a few estimates involve the costs of mitigating environmental damages (e.g., the costs of avoiding the effects of sea level rise brought on by global warming).

Effects on climate are calculated based on the assumption that a doubling of the CO_2 concentration in the atmosphere will lead to a general rise of temperature levels of 1.5-5.5 degrees C, resulting in a rise of the main sea level by app. 25-165 cm, and lead to severe damage in coastal areas. For Germany this will result in a necessary increase in height of the coastal defence works of a total length of app. 1000 km. The costs are recalculated to costs per year over a period of 50 years and only related to CO_2 emissions from fossil fuels. The value transferred to CO_2 emissions give a very small estimate of 7-14 \$/t CO_2 in 1982. These costs being mitigation costs are not directly comparable to the CO_2 costs calculated in other studies as damage costs.

Valuation of health risk has been estimated based on other studies, which assume that air pollution will lead to decreased availability of the production factor labour or to casualties of the production factor labour. Therefore health risk has been valued as loss in production per year and the term VSL has not been used.

5 Comparison of results

Table 5.1 gives an overview of the methods used, the costs related to global warming and the value of a statistical life used in the different studies. The results shown for natural gas and coal are for all studies in US$ year 1995. The other costs are related to the reference year for the study.

The Swiss study and Hohmeyers study are "top-down" studies, while the rest of the studies are "bottom-up" studies using the damage function approach. Only the Swiss study, Hohmeyer and the ExternE study monetise global warming. Hohmeyer uses mitigation costs for monetisation resulting in a very low cost for global warming. The estimate for natural gas from Hohmeyer is therefore comparable to the other studies without global warming. The Swiss study has the highest estimate for natural gas (9.1-13.6 UScent/kWh), but uses also high costs for global warming. The highest value for global warming in the ExternE study (139 ECU/t CO2 (180 $)) equals the value used in the Swiss study. If this value is used for global warming in the ExternE study the estimate for natural gas is10.15 UScent/kWh, which corresponds to the Swiss estimate.

A conspicuous parameter is the value of VSL used in the Indian study (9320$) compared to the values used in the other studies (around 3-4 mio $). However, the results for coal in India are still high compared to the other studies.

Table 5.1 Comparison of the different studies

	ExternE	IEA	New York	Northern State	US-EC	India	Swiss	Hohmeyer
Approach	Bottom-up	Bottom-up	Bottom-up		Bottom-up	Bottom-up	Top-down	Top-down
Costs	Damage costs	Damage costs	Damage costs	Damage costs	Damage costs	Damage costs	Damage costs	Damage costs
Methodology	Damage function	Damage function	Damage function	Damage function	Damage function	Damage function	Damage function	Other studies approaches
Atm. Modelling	Gaussian plume model, Receptor orientated Lagrangian model No ozone model	Two models for transport and chemistry of pollutants	Annual average model, Simple peak model, Ozone model	ISCST2-model (Gaussian type)	Gaussian plume models	Gaussian model	No dispersion models	No dispersion models
Dose-response	Linear	Linear	Default high, central and low parameters	Linear, logarithmic, exponentiel	Linear	Linear, logarithmic	Based on other studies	Based on other studies
Damages	Local, regional, global	Local, regional, global	Local, regional, (global)	Local, regional	Local, regional	Regional (SO_2, particulates)	Regional, Global	Local, regional ,global
Global warming	3.8-139 ECU/t CO_2 (18 ECU as central)	CO_2 storage	0 \$/t CO_2	-	-	-	160-230 \$/ t CO_2	0.03-0.05DM/t CO_2 (mitigation costs)
Valuation Methods	WTP, market price, Hedonic pricing, CV	WTP, market price, Hedonic pricing, CV	CCV, CV	relationship betw. healthstate index and WTP	WTP, CV, Travel costs	Market price, Loss in rent	WTP Market price	WTP Market price
VSL	3.1 MECU	3 million \$	4 mio \$(< 65) 3 mio \$(>= 65))	3.6 mio. US\$,	?	287230 rupees (9320 \$)	?	-
Discount rate	3%	1.5%	?	?	3%	?	?	?
Reference year	1995	1994	1995	1993	1992	1994	1990	1982
Estimate for natural gas (1995)	9-101.5 mECU/kWh (19 mECU/kWh as central)	0.8-3.1 mECU/kWh	0.3 mECU/kWh	-	0. 1-0.3 mECU/kWh		91-136 mECU/kWh	10-57 mECU/kWh
Estimate for coal (1995)	-	-0.8-7.3 mECU/kWh	6.1 mECU/kWh	-	0.6-1.4 mECU/kWh	12.6 mECU/kWh		10-57 mECU/kWh

6 Comparison of results using three different methodologies

Three studies using different methodologies have been compared in details. A comparison of the impacts and damage costs related to air emissions has been made for the three studies. The studies considered are the following:

- ExternE National Implementation
- The New York Electricity Externality Study
- The Northern States Power Company Study

The studies have been compared two and two in that way, that both The New York Electricity Externality Study and The Northern States Power Company Study have been compared to the ExternE study, but these two studies have not been compared to each other.

The external costs will be estimated for the same reference plant using the dispersion models, dose-response functions, impacts and monetary values from the three studies. The estimates from the three studies will be compared, and a more detailed analysis will be performed in relation to human health, which is the dominating impact in all externality studies.

6.1 Reference plant

The reference plant used for assessment of externalities is a pulverised coal-fired plant with a capacity of 300 MW and an electricity output of 1700 GWh per year. The detailed data for the plant is shown in Table 6.1.

Table 6.1 Operationel data for the pulverised coal-fired plant, used as reference

Capacity:	300.0 [MW]
Full load hours per year:	5700 [h]
SO_2 Emissions:	133.0 [mg/Nm3]
NOx Emissions:	143.0 [mg/Nm3]
PM10 Emissions:	11.0 [mg/Nm3]
Stack height:	150.0 [m]
Stack diameter:	4.0 [m]
Flue gas volume stream:	1357000.0 [Nm3/h]
Flue gas temperature:	400.0 [K]
Surface elevation at site:	15.0 [m]
Anemometer height:	150.0 [m]

The above listed data are used as input in the EXMOD model in the New York Study as well as in the EcoSense model used in the ExternE study. The impacts from this plant have in this way been calculated in EXMOD as well as in EcoSense. However, EXMOD only includes data for emission levels and population for a part of the USA, while EcoSense only includes data for Europe. Therefore the same plant has been located in two different sites. Using EXMOD, the plant s located in the Capital District of New York State, which is a suburban site outside of Albany, while the same plant in EcoSense is located in Roskilde, Denmark.

In the Northern State Study the external costs are estimated in $/tonne emission for different scenarios, consisting of a variation of plants. The reference plant is therefore not used as input in the study. In stead the external costs for the three scenarios, estimated in $/tonnes pollutant, are multiplied with the emissions from the 300 MW reference plant, which should make the estimated external costs comparable. Still, the dispersion is estimated for a variation of plants with different stack heights, which may give rise to some differences in dispersion and impacts.

7 The ExternE National Implementation Study

An overview of the ExternE National Implementation Study was given in Chapter 4.2. The following gives an overview of the computer model, EcoSense, which have been used as tool in the assessment of externalities and a more detailed description will be given of the human health effects, included in the EcoSense model. The description is based on material from (Schleisner, L. et al., 1997appl).

7.1 The EcoSense Model

The impacts on human health, crops, forests and materials due to air-borne emissions are in the ExternE project quantified using the computer tool Ecosense. Although global warming is certainly among the priority impacts related to air pollution, EcoSense does not cover this impact category because of the very different mechanism and global nature of impact. Version 2.0 of EcoSense covers 13 pollutants, including the 'classical' pollutants SO_2, NO_x, particulates and CO, as well as some of the most important heavy metals and hydrocarbons, but does not include impacts from radioactive nuclides.

Figure 7.1 shows the modular structure of the EcoSense model.

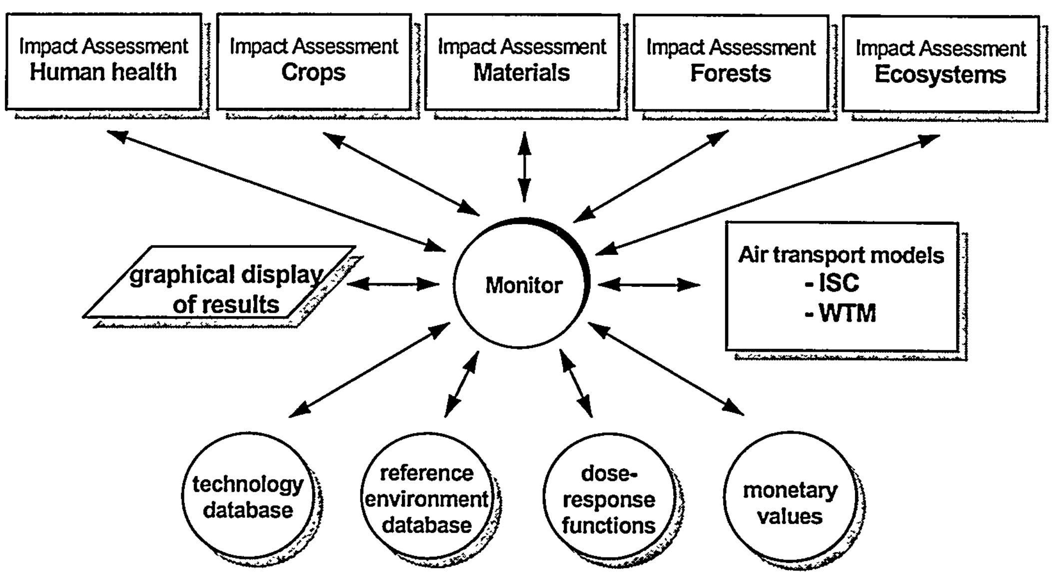

Figure 7.1 Structure of the EcoSense model

7.1.1 Reference Technology Database

The reference technology database consists of technical data describing data for the power plant that are mainly related to air quality modelling, including e.g. emission factors, flue gas characteristics, stack geometry and the geographic co-ordinates of the site.

7.1.2 Reference Environment Database

The reference environment database provides data on the distribution of receptors, meteorology as well as a European wide emission inventory. All geographical information is organised using the EUROGRID co-ordinate system, which defines equal-area projection gridcells of 10 000 km^2 and 100 km^2 (Bonnefous a. Despres, 1989), covering all EU and European non-EU countries.

7.1.3 Exposure-Response Functions

Using an interactive interface, the user can define any exposure-effect model as a mathematical expression. The user-defined function is stored as a string in the database, which is interpreted by the respective impact assessment module at runtime. All exposure-response functions compiled by the various 'area experts' of the ExternE Maintenance Project are stored in the database.

7.1.4 Monetary Values

The database provides monetary values for most of the impact categories following the recommendations of the ExternE economic valuation task group. In some cases there are alternative values to carry out sensitivity analysis.

7.1.5 Air Quality Models

To cover different pollutants and different scales, EcoSense provides two air transport models completely integrated into the system:

- The Industrial Source Complex Model (ISC) is a Gaussian plume model developed by the US-EPA (Brode and Wang, 1992). The ISC is used for transport modelling of primary air pollutants (SO_2, NO_x, and particulates) on a local scale.
- The Windrose Trajectory Model (WTM) is a user-configurable trajectory model based on the windrose approach of the Harwell Trajectory Model developed at Harwell Laboratory, UK (Derwent, Dollard, Metcalfe, 1988). For current applications, the WTM is configured to resemble the atmospheric chemistry of the Harwell Trajectory Model. The WTM is used to estimate the concentration and deposition of acid species on a European wide scale.

The estimates for the regional range are obtained by using the atmospheric transport model WTM. This model takes into account the chemical conversion of SO_2 and NO_x into aerosols. The estimates for the local range are obtained by using the ISC model for transport modelling of primary pollutants (SO_2, NO_x and particulates).

The impacts estimated in the EcoSense model is the following:
- Human health impacts
- Impacts on crops
- Impacts on materials

7.2 Human health impacts

In Ecosense exposure-response functions are available for aerosols, SO_2 and PM10. Table 7.1 shows the exposure-response functions, which are used for the impact analysis of human health.

Table 7.1Exposure-response functions used for the impact analysis of human health

Health impact	Pollutant	Impact category	Monet. val. ECU	Source
Mortality				
Acute mortality	PM_{10}, aero.	Total pop.	2600000	Schwartz (93)
Chronic mortality	PM_{10}, aero.	Total pop.	2600000	Pope et al. (95)
Morbidity				
Chronic AOD	PM_{10}, aero	Adults	138	Abbey et al. (95)
Restricted activity days	PM_{10}, aero	Adults	62.4	Ostro (87)
Short breath for asthmatics	PM_{10}, aero	Asthmatics	31.3	Ostro (91)
Chronic bronchitis	PM_{10}, aero	Children	138	Dockery et al. (89)
Chronic cough	PM_{10}, aero	Children	138	Dockery et al. (89)
Hosp. visits. childhood croup	PM_{10}, aero	Children	186	Schwartz et al. (91)
Cardiac hospital admissions	PM_{10}, aero	Total pop.	6600	Burnett et al. (95)
Emerg. room visits for asthma	PM_{10}, aero	Total pop.	186	Schwartz (93)/Bates (90)
Emerg. room visits for COPD	PM_{10}, aero	Total pop.	186	Sunyer et al. (93)
COPD hospital admissions	PM_{10}, aero	Total pop.	6600	Schwartz/Burnett (94)
Symptom days	PM_{10}, aero	Total pop.	6.3	Krupnick et al. (90)
Restricted hospital admissions	PM_{10}, aero.	Total pop.	6600	Schwartz/Burnett (94)

In the model impacts related to SO_2, NOx and particulates, are divided into impacts affecting adults, children and the total population.

The following impacts are affecting adults, accounting for 80% of the population:

- Congestive heart failure
- 'Chronic' YOLL
- Restricted activity days
- Chronic bronchitis
- Asthma

Congestive heart failure is an impact only attacking elderly people in the age 65 or older. This group accounts for 14% of the total population.

The life years (YOLL) lost approach is used in cases where the hazard has a significant latency period before impact, or where the probability of survival after impact is altered over a prolonged period. The YOLL approach is particularly recommended for deaths arising from illnesses linked to exposure to air pollution. The value will depend on a number of factors, such as how long it takes for the exposure to result in the illness and how long a survival period the individual has after contracting the disease. Chronic YOLL is linked to long term (chronic) exposure to non-carcinogenic air pollutants.

Restricted activity days are defined as days on which illness prevents an individual from engaging in some or all of his or her individual activities. This includes days spent in bed, days missed from work, and days with minor activity restrictions because of illness.

Chronic bronchitis is linked to long term (chronic) exposure to the non-carcinogenic air pollutants and is measured in cases.

Asthma is registred as bronchodilator usage, cough and lower resperatory symptoms. Bron-chodilator usage is stated as cases, while cough and lower resperatory symptoms are stated as days with these symptoms.

Children, accounting for 20% of the population, are affected by chronic cough, chronic bronchitis and asthma.

The entire population are affected by these impacts:

- Respiratory hospital admissions
- Emergency rooms visit (ERV)
- Cerebrovascular hospital admissions
- Acute YOLL

Emergency rooms visit is in the EcoSense model divided into ERV for COPD, ERV for asthma and ERV for croup in pre school children.

All the damages are estimated in cases per TWh using the above mentioned dose-response functions. The damages are multiplied with monetary values in order to calculate the external costs. The monetary values used for the different damages are shown in the table.

7.3 Impacts on crops

In Ecosense exposure-response functions are available for acid deposition and SO_2. The exposure-response functions and the monetary values, which have been used for the impact analysis of crops are listed in Table 7.2.

Table 7.2 Exposure-response functions used for the impact analysis of crops

Sub-receptor	Pollutant	Impact	Monetary value in ECU	Source
Barley	SO_2	yield loss in dt	4.8	Roberts (1984)
Oats	SO_2	yield loss in dt	5.0	Roberts (1984)
Rye	SO_2	yield loss in dt	13.9	Roberts (1984)
Wheat	SO_2	yield loss in dt	8.6	Roberts (1984)
Total	Acid deposition	Additional lime needed in kg	0.015	CEC (1993)

The SO_2 impact is as well local as regional, while the acid deposition is only regional. Therefore there is no liming externalities on the local level. The monetary values used are based on the prices given in FAO Quarterly Bulletin of Statistics, Vol.4, 1993.

7.4 Impacts on materials

The exposure-response functions, which have been used for the impact analysis of materials are listed in Table 7.3. Both SO_2 and wet acid deposition gives regional impacts as shown in table. The monetary values used are also shown.

Table 7.3 Exposure-response functions used for the impact analysis of materials

Sub-receptor	Pollutant	Impact	Monetary value ECU	Source
Galvanised steel	SO_2, acid dep.	maintn. surface (m^2)	29.4	Kucera et al. (1995)
Limestone	SO_2, acid dep.	maintn. surface (m^2)	245	Kucera et al. (1995)
Mortar	SO_2, acid dep.	maintn. surface (m^2)	27	Kucera et al. (1995)
Natural stone	SO_2, acid dep.	maintn. surface (m^2)	245	Kucera et al. (1995)
Paint	SO_2, acid dep.	maintn. surface (m^2)	11	Haynie (1986)
Rendering	SO_2, acid dep.	maintn. surface (m^2)	27	Kucera et al. (1995)
Sandstone	SO_2, acid dep.	maintn. surface (m^2)	245	Kucera et al. (1995)
Zinc	SO_2, acid dep.	maintn. surface (m^2)	22	Kucera et al. (1995)

8 The New York Electricity Externality Study

An overview has been given of the New York Electricity Externality Study in chapter 4.3. In this study the EXMOD model is used, which will be described in the following together with a more detailed description of the human health effects, included in the EXMOD model. The description is based on materiel from (Rowe et al, 1995).

8.1 The EXMOD model

The EXMOD model is based on the "damage function" approach, which goes through a multi-step process. The first step is the calculation of emissions of the facility. The second step is the distribution of those emissions to various receptors. The next step is the calculation of impacts on those receptors, such as reduced crop production or additional occurrences of asthma attacks. After the physical impacts are calculated, monetary valuations are applied to the impacts to calculate damages in dollar amounts.

The externalities considered range from the human health effects of various atmospheric pollutants, to the future contamination of ground water from ash disposal sites, and to the effect on crop production from changes in ozone levels.

8.1.1 Environment Database

Built into EXMOD are extensive demographic, meteorological and air quality databases which represent New York, and the nearby states and Canadian provinces. The EXMOD model has been developed explicitly for New York State, but can be adapted to a wide variety of other states or regions by changing the underlying environmental and demographic data sets.

The key components for evaluating these externalities are the extensive environmental and demographic databases that have been incorporated into EXMOD. In EXMOD, all of New York State and, to a lesser extent, all adjacent states and Canadian provinces are represented by geographic groupings of census tracts (called "supertracts"). Each of the supertracts is represented by detailed air quality and demographic data, along with basic information such as land area and elevation. The supertracts provide the basis for many of the externality calculations. In addition, EXMOD contains a large set of meteorological data for the air quality models and crop production data for the agricultural damage calculations.

8.1.2 Air Quality Models

EXMOD uses several standard air quality models to calculate the dispersion of air emissions and changes in ambient air quality. The air quality models, which are used in EXMOD is the following:

- The ISC2LT model calculates annual averages of ambient concentrations. Many of the air-related environmental externalities have damage functions that use measures of annual or long-term average concentrations as explanatory variables. Here the results from the ISC2LT model can be used directly.
- SCREEN 2 uses stack parameters and emission rates to calculate 1-hour ground level concentrations. This model is used for damage functions requiring short term averages. SCREEN 2 is applied to a distance of 80 km from the plant.
- The SLIM 3 model is used to calculate annual average impacts at long range (more than 50 km from the plant). The model incorporates terms for wet and dry deposition of gases and particles, and for chemical conversion of SO_2 and NO_x.

The impacts, estimated in the EXMOD model, are impacts to air, impacts to water and impacts to land/waste. In this report only impacts to air are described, which have been divided into human health impacts, impacts on crops and impacts on materials. Visibility impacts are also estimated in the model, but are not described in this report.

8.2 Human health impacts

Human health impacts are the dominating impacts to air, where mortality and morbidity are the most important externality groups.

Mortality and morbidity due to the emissions to air from a power plant are quantified and monetised for the following effects:

- Effects of airborne particulate matter
- Effects of lead
- Effects of mercury
- Effects of ozone
- Effects of air toxics

Mortality and morbidity related to CO_2 emissions has not been quantified and monetised.

8.2.1 Effects of airborne particulate matter

Particulates are in this study measured as PM_{10}, which corresponds to all particulates at 10 μm or below (including sulphates, nitrates and acid aerosols).

For mortality the VSL approach is used with a central estimate of 4 million $ for the WTP for changes in risks of death, based on review of 4 studies: Fischer et al., Cropper and Freeman, Viscusi, and Miller. The WTP for older people is expected to be lower than for younger people, and the central estimate of VSL has therefore been estimated to 3 million $. The same VSL estimate is used for children as for adults. If it is not possible to divide the population into groups above and below 65 years of age a central estimate of 3.3 million $ for the total population is used.

Related to morbidity many different types of human health effects have been associated with particulates. In this study the following health effects have been quantified and monetised:

- Chronic bronchitis in adults
- Respiratory hospital admissions
- Emergency room visits
- Asthma attacks
- Restricted activity days
- Acute respiratory symptoms
- Bronchitis in children

Chronic bronchitis in adults

The health effects of chronic bronchitis include persistent symptoms of cough and phlegm, limits in physical activities and ongoing medical care. The monetary value of this decease is based on WTP results from Viscusi et al., which reflect the maximum amount the respondents (having relatives with chronic bronchitis, asthma or emphysema) would be willing to pay at the present time to avoid this entire set of impacts for the rest of their lives.

The elasticity estimate for numbers of symptoms is used to scale the estimates for a severe chronic bronchitis case to better reflect WTP to avoid a more typical case. The elasticity estimate is based on results from Krupnick and Cropper for a combined analysis of chronic bronchitis, asthma and emphysema. This results in a central estimate of 210,000 $ for an average chronic bronchitis case.

Respiratory hospital admissions

There exists no WTP estimates for respiratory hospital admissions. Therefore cost of illness (COI) estimates (financial losses such as medical expenses and lost income) have been used. The central estimate (14,000 $) is calculated using the following formula:

Central estimate of RHA = [(L*W) + C] * WTP/COI

where

L = length of stay in hospital due to chronic bronchitis or emphysema
(reported to 9.5 days from the Heart, Lung and Blood Institute)
W = average daily wage 1992 in New York State (125 $)
C = average hospital costs for a hospital stay due to respiratory disease
(based on Krupnick and Cropper)
WTP/COI = ratio of WTP to COI which has a default value of 2.

Emergency room visits

WTP estimates for emergency room visit are not available, and COI estimates are used. The central estimate (530 $) is calculated using the following formula:

Central estimate of ERV = [W + C] * WTP/COI

where

W = average daily wage 1992 in New York State (125 $)
C = average ERV fees (based on Rowe et al.)
WTP/COI = ratio of WTP to COI which has a default value of 2.

Asthma attacks

WTP estimates are used based on Krupnick and Kopp (which relies on Rowe and Chestnut). The central estimate is 34 $ per day with asthma attack, based on asthmatics estimates of WTP to prevent an increase in "bad asthma days".

Restricted activity days

WTP estimates for preventing a restricted activity day are not available. A central estimate (70 $) has therefore been estimated for an average restricted activity day using available COI data and WTP estimates for days of symptoms. The following formula is used:

Central estimate of RAD = [0.20 * W * WTP/COI] + 0.80 * C

where

W = average daily wage 1992 in New York State (125 $)
WTP/COI = ratio of WTP to COI which has a default value of 2
C = WTP to avoid a day with symptoms such as serious or minor cough (based on Krupnick and Kopp (which relies on Loehman))

In the formula it is assumed that 20 % of the restricted activity days due to air pollution are bed-disability days, while 80 % of the restricted activity days are days with minor symptoms such as serious or minor cough.

Acute respiratory symptoms

Days with acute respiratory symptoms are days with coughing, congestion or throat irritation. These symptoms result not necessarily in any changes in the person's activities on that day. The health effects are therefore included, but not limited to RAD, and RAD may therefore be subtracted from days with acute respiratory symptoms to avoid double counting.

The monetary value for days with acute respiratory symptoms is therefore a value of for the days where symptoms are noticeable but do not restrict normal activities for that day. The central monetary estimate per day with acute respiratory symptoms (10 $) is based on WTP from Loehman et al. and Tolley et al..

Bronchitis in children

WTP estimates for bronchitis in children are not available. A central annual estimate (270 $) has therefore been estimated using available COI data for medical treatment. The following formula is used:

Central estimate of B per year = C * WTP/COI

where

C = average annual medical treatment costs for a child with bronchitis (based on Krupnick and Cropper)
WTP/COI = ratio of WTP to COI which has a default value of 2

8.2.2 Effects of lead

Lead emissions behave as particulates, and concentrations typically peak within 10-30 km from the site depending on stack height, meteorological conditions and terrain features. Based on the emission rates, the air dispersion models compute changes in ambient air lead concentrations for each receptor cell. These changes in ambient air concentrations are used in the damage assessment.

8.2.3 Effects of mercury

A method has been developed to quantify damages for selected human health effects from mercury. However, the method involves a considerable number of assumptions for which there are only a limited number of literature and data. Therefore, the detailed method is not included in the model, and instead an estimate in $/pound damage from different case studies are used as default values. For coal the central estimate is 20 $ per pound mercury emitted.

8.2.4 Effects of ozone

The emission of ozone will cause as well mortality as morbidity cases for the whole population. The cases of morbidity will be a number of respiratory hospital admissions, asthma attacks, minor restricted activity days and acute respiratory symptoms.

The quantification and valuation of the emission of ozone has been included in the EXMOD model. Given user inputs like location and type, size and load factor for the facility, the air quality model provides changes in ambient O_3 concentrations, which is combined with the relevant affected population to determine the extent of injuries. The predicted change in injuries is then valued to determine damages.

8.2.5 Effects of air toxics

Air toxics are associated with combustion of fuel in the power plant. The most important toxic agents are the following: Arsenic, beryllium, cadmium, chronium, nickel, dioxin, formaldehyde, furans, PCBs and POMs. The central estimates of extra cancers per ton of these emissions per year are shown in Table 8.1. The estimates are only shown for coal.

Table 8.1 Central estimates of extra cancers per ton of air toxics

	Urban /Suburban area	Rural area
Arsenic	3.37 e-3	2.81 e-4
Beryllium	1.88 e-3	1.57 e-4
Cadmium	1.41 e-3	1.17 e-4
Chronium	9.39 e-3	7.83 e-4
Nickel	1.88 e-4	1.57 e-5
Dioxin	NA	NA
Formaldehyde	1.51 e-5	1.26 e-6
Furans	NA	NA
PCBs	NA	NA
POMs	2.46 e-2	2.05 e-3

NA=not available

When a new cancer case occurs, it is not known what will be the outcome. Some people survive after treatment while others die. The valuation of new cancer cases is based on WTP using the following formula:

Cancer WTP = (survival rate * NFC) + (1 – survival rate) * VSL

where

NFC = the value per non fatal cancer case (204,000 $)
VSL = value of statistical life (3.3 million $)

In the central estimate an average five-year survival rate of 51 % is used for all cancer patients in the US resulting in a central estimate of 1.7 million per new cancer case.

8.2.6 Summary

The monetary values together with the respective sources for each of the damages of human health are summarised in Table 8.2.

Table 8.2 Monetary values used in EXMOD and the respective sources

Impacts to air	Externality group	Monetary value	Source
Particulate matter (incl. sulphates, nitrates, aerosols)	Mortality	3.3 mio $	Fischer et al, Cropper and Freeman, Viscusi, Miller
	Over 65	3 mio $	
	Under 65	4 mio $	
	Morbidity		
	Chronic bronchitis in adults	210,000 $	Krupnick/ Cropper
	Respiratory hosp. adm.	14,000 $	Krupnick/ Cropper
	Emergency room visits	530 $	Rowe et al.
	Asthma attacks	34 $	Krupnick/ Kopp
	Restricted activity days	70 $	Krupnick/ Kopp (Loehman)
	Acute respiratory symptoms	10 $	Loehman et al., Tolley et al.
	Bronchitis in children	270 $	Krupnick and Cropper
Lead emissions	Mortality morbidity		
Mercury emissions	Morbidity	20 $/pound	
Ambient ozone	Mortality Morbidity		
Air toxics emissions	Cancer mortality and morbidity	1.7 mio $	

8.3 Impacts on crops

In the EXMOD model impacts to commercial crops in New York are included. The impacts on crops are related to changes in ambient ozone concentrations, and not as a function of SO_2 like in EcoSense. The analysis has focused on five important agronomic crops for which dose-response data are available: corn, soybeans, wheat, alfalfa hay and other hay. The exposure-response functions and the monetary values, which have been used for the impact analysis of these crops are listed in Table 8.3.

Table 8.3 Exposure-response functions used for the impact analysis of crops

Sub-receptor	Pollutant	Impact	Monetary value in US$	Source
Corn	Ozone	yield loss in bushel	2.76	New York State Dep. of Agri. (1990)
Soybean		yield loss in bushel	6.07	
Wheat		yield loss in bushel	3.22	
Hay (Alfalfa)		yield loss in ton	86.75	
Other hay		yield loss in ton	62.25	

The monetary values used are an average for 1988-1990 and are based on prices from the New York State Department of Agriculture and Market, 1990.

On average across New York, the five crops identified in Table 8.3 account for about 73% of the harvested acreage in New York. Other crops have been included by dividing the damages from the five crops by the percent of harvested acreage accounted for by the five crops.

8.4 Impacts on materials

The material damages from air pollutants included in the EXMOD model are due to particulate matter and SO_2 . The estimates of economic effects include household cleaning and maintenance associated with PM and SO_2, and maintenance cost estimates for galvanised steel based on SO_2 damage functions.

The impacts are divided into material soiling damage from PM_{10} and material damage from SO_2 . For material soiling damage a central monetary estimate of 2.80 $ is used per household per $\mu g/m^3$ anually, while the central estimate for annual SO_2 materials damage per household per $\mu g/m^3$ is 1.85 $.

9 The Northern States Power Company Study

An overview of the Northern State Power Company Study has been given in chapter 4.4. Here a more detailed description will be given of the human health effects. The description is based on materiel from (Triangle Economic Research, 1995).

The study includes impacts to air only, and only connected to the production of electricity by coal- or gas-fired power plants. The study includes 6 pollutants in total: Particulate Matter (PM_{10}), Carbon Monoxide (CO), Nitrogen Oxide (NO_x), Sulphur Dioxide (SO_2), Lead (Pb) and Ozone (O_3). Additionally, Carbon Dioxide (CO_2) and Mercury (Hg) were examined, but were excluded from the analysis due to lack of data and methodological uncertainties.

9.1 Modelling dispersion

The model chosen for the dispersion analyses is the ISCST2, which is the model recommended by the U.S. EPA for use in estimating impacts from sources in non-complex terrain (U.S. EPA, 1990). Non-complex terrain is defined as terrain in which the elevation at each receptor is lower than the stack height. Methodologically the ISCST2 model is of the Gaussian-formulation type, and it is designed for estimating hourly impacts from multiple sources using sequential hourly meteorological data for an entire year.

Receptors locations were chosen with the intent to represent a cross section of the area's population and natural resources, and to capture variations in air quality from one location to another. A receptor is simply the location at which pollution concentrations are estimated using the dispersion model, and subsequently these concentrations are used to determine the exposure. Zip codes were used as the geographical unit for the receptor location, with receptors placed in the town in which the post office was located. A total of 619 receptors were selected in the states of Minnesota, Wisconsin and South Dakota. Geographically, the study was restricted to the area of NSP, that is Minnesota, western Wisconsin and south-eastern South Dakota.

The following impacts are included in the study:

- Human health effects
- Agricultural effects in the form of reduced crop yields
- Materials damages

Visibility damages from the scatterings of light by pollution are also estimated in the study, but not described in this report.

9.2 Human health effects

As mentioned only impacts to air are investigated and only connected to six pollutants. The impacts on human health from these six pollutants are shown in Table 9.1 below.

Table 9.1 Impacts on human health

Impacts to air	Externality group
Particulate matter	Mortality Respiratory illness Symptomatic effects
NO_x nitrates	Eye irritation
Lead emissions	Neurotoxic effects Effects on the cardiovascular system Effects on the fetus
CO carbon oxide	Headache
Ambient ozone	Respiratory symptoms in adult non-smokers Chronic asthma in children
so_2 acid deposition	Chest discomfort

The human health effects mentioned in Table 9.1 are those taken into account in the analyses. In the following the effects taken into account are discussed more thoroughly for each of the impacts to air.

9.2.1 Impacts from SO_2-emissions

- Chest discomfort

Chest discomfort is included in the analyses in the study, based on a number of findings by other researchers. The dose-response function for chest discomfort are as follows:

$$\Delta Cases = 1.88*(BC/Pop)*(Pop-BC)*\Delta SO_2$$

where

BC = the number of base cases in population
Pop = the region's population
ΔSO_2 = the change in daily SO_2 measured in ppm

The following impacts were discussed, but not found to be relevant in the NSP-study: Lung function changes, symptomatic effects in asthmatics, emergency rooms visits and higher mortality rates caused by short-term exposures.

9.2.2 Impacts from Particulate matter

Particulate matter is notified as PM_{10}, signifying that it covers particles less than 10μm in diameter. The following effects are included in the study:

- Mortality
- Respiratory illness
- Symptomatic effects

For mortality a meta analysis of 11 concentration-response studies for mortality effects of particulate matters were undertaken. What concerns respiratory illness and symptomatic effects a critical review was performed and the results from a few selected studies used in the analysis.

The following impacts were discussed, but not found to be relevant in the NSP-study: Decreased pulmonary function and morphological damage.

9.2.3 Impacts from NO_x

A number of studies have concentrated on the risk of NO_x-emissions. NO_2 poses the more serious health risks of NO_x and in the NSP-study main attention is paid to this one and its related health effects. Though, to calculate damages a model for NO_x concentrations had to be developed as a proxy for NO_2.

Only eye irritation is included in the study.

- Eye irritation

A simplified concentration-response function was used:

$$\Delta Cases = 0.883 * BC/Pop * (Pop - BC) * \Delta NO_2.$$

Where

BC is the number of base cases in the population
Pop is the considered population
ΔNO_2 is the change in daily maximum NO_2 levels measured in ppm.

The following impacts were discussed, but not found to be relevant in the NSP-study: Morbidity in children under age 12, emphysema and morbidity in asthmatics

9.2.4 Impacts from Ozone

The following effects from ozone emissions are included in the study:

- Respiratory symptoms in adult non-smokers
- Chronic asthma in children

For both the effects are based on selected studies from the literature.

The following impacts were discussed, but not found to be relevant in the NSP-study: Acute respiratory disease, aggravation of existing respiratory disease, exercise performance and worker productivity, morphological effects due to chronic exposure, altered host defence and mortality.

9.2.5 Impacts from CO

Included in the study is:

- Headache

The effects of CO on headache are based on one specific study.

The following impacts were discussed, but not found to be relevant in the NSP-study: Reduced time to onset of angina in patients with ischemic heart disease, physical effects related to oxygen deprivation in sensitive subgroups and sensitive body organs, central nervous system effects on compensatory tracking, event monitoring, and attention and effects on physical endurance and aerobic activity/cardiorespiratory response.

9.2.6 Impacts from lead

Elevated blood lead levels have been linked to a number of adverse health effects, some established with more certainty than others. Included in the NSP damage-cost study is:

- Neurotoxic effects
- Effects of lead on the cardiovascular system
- Effects on the fetus

For all three mentioned the effects are based on selected studies from the literature.

The following impacts were discussed, but not found to be relevant in the NSP-study: Other neurotoxic effects, effects of lead on heme biosynthesis and red blood cell physiology, effects on kidney, effects on reproduction and fertility, effects on immune system, effects on gastrointestinal system and carcinogenic effects.

9.3 Valuation of human health effects

9.3.1 Short term health effects

The study uses a relationship between health-state indexes and Willingness to pay (WTP) to avoid different health effects.

A health-state index offers an operational framework for classifying individuals according to the level of mobility, physical activity, social activity and most severe symptom or problem complex they may experience. These indexes are based on the idea that health is defined by both objective and subjective components of well-being. Ill health can be described as some deviation from an ideal well-being. Hence, health-state indexes were conceived to provide qualitative measure of health by placing individuals along a close-interval scale.

A meta analysis was performed using a number of studies giving WTP for a number of different health effects. These values are then used for any short-term health effect for which it is possible to assign a health state index score. Thus it is possible to establish WTP for an entire range of short-term health effects.

The model predicts WTP as a function of Health index score and the number of days that a health effect is reduced, and assumes that WTP is equal to 0 when the health index equals 1 (perfect health). By applying the model to the short-term health effects calculated for each of the planning scenarios, it is possible to calculate the benefits and losses associated with each scenario.

Table 9.2 Predicted WTP-values for reductions in short-term health effects.

Health effect	1- health index	Average number of days	Mean (1993$)	90% confidence interval (1993$)
Acute bronchitis	.378	2	148	48-347
Chest discomfort	.299	1	35	12-82
Cough	.318	2.2	76	25-179
Croup	.378	3	195	64-457
Eye irritation	.23	1	15	5-35
Headache	.305	1	38	12-89
Lower respiratory effect	.318	1.4	56	18-131
Upper respiratory effect	.231	1.4	19	6-45

Thus, an acute bronchitis is typically expected to last 2 days and the mean average cost will be 148$ (1993-US$). For most of the health effects there are a considerable variation in the calculated costs. As for acute bronchitis the 90% confidence–level gives a variation of 48-347 US$, more than a factor of 2.

When comparing with the results of others it seems that those obtained in the NSP-study are well inline with most. There might be quite a difference between the estimated mean values, but almost all WTP estimates from other studies compared with lie well within the confidence interval estimated in the NSP-study.

9.3.2 Chronic health effects

A number of health effects are long term, chronic conditions. The health state indexes are designed for small differences, such as between one versus seven days of a health effect. To take into account the long term chronic health effects a number of studies especially looking onto the long term effects have been used.

The model is specified for a once-and-for-all change in the number of people with a given effect, rather than based on increases in accumulated exposure. Theoretically, the last mentioned approach is the more correct one, because the number of effects increase over time, while the used approach assumes the full effect occurs in the first year, which might lead to an overestimation of effects.

Table 9.3 The used WTP values for chronic health effects (1993 US$)

Chronic effects	WTP value (annual $)	Standard error
Asthma	439	5.6
Emphysema, chronic bronchitis and asthma	8900	3300
Chronic cough	2900	1500
Diastolic blood pressure (1 point)	285	171
IQ score (1 point)	160	97

Only a limited number of relevant studies have been available for the evaluation of chronic effects. In reality a number of the given estimates are based on the one and only study available for that effect. Thus the results are estimated with a considerable spread, cf. Table 9.3.

9.3.3 Mortality

In the NSP-study the concept of the value of statistical life (VSL) is used as the basis for valuing mortality risk reductions. As the basis for the VSL evaluations a small conceptual model, based on the utility functions of individuals, is developed.

The value of a statistical life is the sum of a group of individuals' WTP divided by the change in the expected number of lives lost in the population:

$$VSL = \Sigma_i \, WTP_i / (\Delta p * Pop)$$

Where

Δp is the changed in risk
Pop is the considered population

In the meta analysis performed 29 studies were used in total. All of these reported an estimated VSL, a risk level and the basis for this risk level. Most of these studies are based on a wage-risk approach.

Table 9.4 shows the main results from four of those studies used in the meta analysis. In general substantial variation in the estimated VSL value is observed within the sample of 29 studies.

The estimated WTP value in the NSP-study corresponds to a VSL of 3.6 mill. US$, which lies well inline with most of the observed range in the literature.

Table 9.4 Selected group of VSL-studies

Study	Risk level	VSL (1993 $)	Compensating differential (1993 $)
Viscusi and Moore (1989)	0.783	8600000	673
Moore and Viscusi (1988)	0.79	6857850	542
Moore and Viscusi (1990)	1.0	17800000	1780
Kniesner and Leeth (1991)	4.36	645186	281

9.4 Valuation of agricultural damages caused by air pollution

Agriculture is one of the most important industries in the considered area, which covers Minnesota, Wisconsin and South Dakota. Thus it was important to include agricultural damages caused by air pollution into the study.

The assessment of agricultural damages focuses on the damages to field crops, mainly because very few studies have evaluated the effects of air pollution on livestock, and concentration-response functions are not available for cattle and milk production.

Major pollutants included in the study are ozone (O_3), sulphur dioxide (SO_2) and nitrogen dioxide (NO_2). The effects of these taken into account in the report are shown in Table 9.5. Because of the mixed effect of acid rain on agriculture, this one is not included in the analysed effects. SO_2 and NO_x are the main contributors to acid rain.

Table 9.5 Agricultural effects of air pollution included in NSP-study

Major pollutants	Effects included in study
O_3	Corn yield reduction Wheat yield reduction Soybean yield reduction Hay (including alfalfa) yield reduction Potato yield reduction
SO_2	Corn yield reduction Wheat yield reduction Soybean yield reduction
NO_2	None
Acid rain	None

For all crops except one (potatoes), the concentration-response functions are taken from the National Crop Loss Assessment Network (NCLAN). From 1980 to 1986 a total of 41 studies were conducted by NCLAN on 14 crops at different sites in the US. Data from these studies form the basis for the concentration-response functions.

What concerns the monetary evaluation the study assumes the farmers to be 'price-takers'. This implies that changes in air pollution levels will not affect national stocks enough to influence the national price. Thus demand-side considerations can be ignored. At the same time the farmers bear all the changes in welfare, with the exception of changes in farm deficiency payments, which can be considered as a welfare transfer between taxpayers and farmers.

9.5 Materials and soiling damages

Most of existing studies on materials and soiling damages tend to concentrate on those issues that are economically important, that is those that are sensitive to pollutants and/or are used abundantly in construction.

The NSP-study evaluates a number of different studies using different approaches to a certain extent. The main conclusion of this review process is that the results should be used with caution. All studies of materials are based on estimates because no exact measures of items like building and materials inventory exists. Many materials studies note the lack of the most important data. On the other hand, models are available for quantification of some of the effects. Thus, in the NSP-study it is chosen to use these models for quantifying the most important materials and soiling damages, namely those stemming from the emission of SO_2 and PM.

10 Comparison of results from ExternE and the New York study

A comparison of the impacts and damage costs related to air emissions has been made for the two studies using the EXMOD model and the EcoSense model for the same plant. The plant is a pulverised coal-fired plant with a capacity of 300 MW. The impacts from this plant have been calculated in EXMOD as well as in EcoSense. However, EXMOD only includes data for emission levels and population for a part of the USA, while EcoSense only includes data for Europe. Therefore the same plant has been located in two different sites. Using EXMOD, the plant is located in the Capital District of New York State, which is a suburban site outside of Albany, while the same plant in EcoSense is located in Roskilde, Denmark. The external costs estimated in Table 10.1 are central estimates.

Table 10.1 Central estimates of external costs for a coal-fired plant

Externalities	The New York study (mECU/kWh)	ExternE (mECU/kWh)
Human health	2.42	9.27
Mortality	*1.71*	*7.97 (32.46)*
Morbidity	*0.70*	*1.30*
Crops	0.002	0.134
Materials	0.10	0.22
Other impacts	0.32	0
Greenhouse gas effect	0	6.10
Total	2.84	15.72 (40.21)

On comparing the externalities for the same power plant estimated in the two studies using different models, we see that the externalities are five times higher in the ExternE study than in the New York study. The difference in the external costs in the two studies reflects differences in impacts, differences in monetary values included in the two studies and especially differences in location of the plants.

The differences in the estimates that are most apparent are the extent of the greenhouse gas effect and the estimation of mortality. The greenhouse gas effect is not included in the New York study (by default monetised to zero), but in the ExternE study four different values of CO_2 have been estimated. In the above table, a value of 18 ECU/t CO_2 has been used. Excluding the global warming effect the estimate in EcoSense is three times higher than the estimate in EXMOD.

The external costs of mortality are four times as high in ExternE as in the New York study. EcoSense normally uses the YOLL approach; the figures in brackets are based on the VSL approach. In EcoSense mortality includes as well chronic as acute mortality, while EXMOD only covers acute mortality. Including as well chronic mortality as the global warming effect in EXMOD, the estimate in EcoSense becomes less than the estimate in EXMOD.

The emission of ozone causes mortality as well as morbidity cases for the population at large and also affects crops. The quantification and valuation of the emission of ozone has been included in the US EXMOD model, while in the case of the EU EcoSense model quantification and valuation of the emission of ozone has not been included. Instead, damages due to ozone are calculated, based on the NO_x emissions related to the plant. However, there is no large difference (14% higher in EXMOD) in the total external costs due to ozone, but the difference in crops is a result of ozone (0.13 mECU/kWh in ExternE).

Other impacts are impacts like visibility loss, which is included in EXMOD, but not in the EcoSense model. Apart from global warming, human health is the dominant impact in both models. The reasons for the differences in the estimates of the effect on human health using the two models will be explained in the following for mortality and morbidity.

10.1 Mortality

In the following table the mortality impacts, monetary values and damage costs are shown as a central estimate for a pulverised coal fired plant using the EXMOD model. For comparison the monetary values used in EcoSense are used for the same impacts. Using these monetary values results in an increase in mortality damage costs of 17 %, only verifying that using the monetary value for VSL from EcoSense give higher results.

Table 10.2 Mortality impacts and damages using EXMOD, central estimate

		EXMOD			EcoSense	Eco/ EXMOD
		Impacts	Mon. val. (mio ECU)	Damage (mECU/kWh)	Mon value (mio ECU)	Damage (mECU/kWh)
Mortality over 65	NO_x	0.377	2.497	0.5512	3.1	0.6843
	PM_{10}	0.2139	2.497	0.3127	3.1	0.3882
	SO_2	0.0764	2.497	0.1117	3.1	0.1387
	Total	**0.6673**		**0.9757**		**1.2111**
Mortality under 65	NO_x	0.0336	3.330	0.0655	3.1	0.0610
	PM_{10}	0.01845	3.330	0.0360	3.1	0.0335
	SO_2	0.00453	3.330	0.0088	3.1	0.0082
	Total	**0.0566**		**0.1103**		**0.1027**
Mortality	Ozone	0.385	2.747	0.6192	3.1	0.6988
Total		**1.1089**		**1.7052**		**2.0126**

The mortality impacts and damages have been calculated for the same plant using EcoSense. Again for comparison the damages have been calculated using the monetary values from EXMOD for these impacts, resulting in smaller damage costs.

Table 10.3 Mortality impacts using EcoSense, central estimate

		EcoSense			EXMOD	Eco/EXMOD
		Impacts	Mon val. (mio ECU)	Damage (mECU/kWh)	Mon value (mio ECU)	Damage (mECU/kWh)
Chronic mortality	PM_{10}	0.5726	3.1	1.7751	2.747	1.5729
	Nitrate	4.3		13.4		11.8122
	Sulfate	4.4		13.6		12.0869
	Total	**9.27**		**28.7451**		**25.4721**
Acute mortality	SO_2	1.198	3.1	3.7138	2.747	3.2909
Mortality total		**10.468**		**32.4589**		**28.7630**

Comparing Table 10.2 and Table 10.3 the external costs of mortality are 19 times as high in ExternE as in the New York study, when using the VSL approach. (EcoSense normally uses the YOLL approach resulting in much smaller external costs for mortality; in this case 7.97 mECU/kWh). However, for comparison mortality has been estimated using the VSL approach for both models.

Comparing the results the most obvious reason for the large difference in mortality impacts for the two models beside the monetary value used, is that as well chronic as acute mortality is included in EcoSense, while only acute mortality is included in EXMOD. Another important factor is that impacts due to ozone is included in EXMOD, but not in EcoSense (ozone has been included in a later version of EcoSense).

The impacts estimated in EcoSense for acute mortality are about twice as high as those estimated in EXMOD.

10.2 Morbidity

10.2.1 Comparison of damage costs for morbidity using the EXMOD model

Table 10.4 shows the morbidity impacts, the monetary values and the damage costs calculated in the EXMOD model. The monetary values used in EcoSense are shown in the table to the right, and these values have been multiplied with the impacts calculated in EXMOD to give comparable results.

Comparing the results on a superior level the total damage costs caused by morbidity are 28% larger using the EXMOD monetary values instead of using the values from EcoSense. Asthma attacks have not been monetised specific in EcoSense, instead the value of bronchodilator usage has been used, assuming that this is a way of avoiding an asthma attack. Impacts like radiation, lead health effects and mercury health effects are not valued in the EcoSense model. Excluding these effects from the EXMOD model results in morbidity impacts of 0.5599, which is still 21% higher than the impacts calculated using EcoSense.

Table 10.4 Morbidity impacts using EXMOD

		EXMOD			EcoSense	Eco/ EXMOD
		Impacts	Mon value (ECU)	Damage (mECU/kWh)	Mon value (ECU)	Damage (mECU/kWh)
Asthma attack	NO_x	1233	28	0.0204	37	0.0267
Asthma attack	PM_{10}	77	28	0.0013	37	0.0017
Asthma attack	SO_2	20	28	0.0003	37	0.0004
	Total			**0.0220**		**0.0288**
Child, acute bronchitis	NO_x	12.06	225	0.0016	225	0.0016
Child, acute bronchitis	PM_{10}	6.64	225	0.0009	225	0.0009
Child, acute bronchitis	SO_2	1.73	225	0.0002	225	0.0002
	Total			**0.0027**		**0.0027**
Case of chr. Bronchitis	NO_x	1.738	174811	0.1779	105000	0.1068
Case of chr. Bronchitis	PM_{10}	0.957	174811	0.0979	105000	0.0588
Case of chr. Bronchitis	SO_2	0.25	174811	0.0256	105000	0.0154
	Total			**0.3014**		**0.1810**
Emergency room visit	NO_x	9.94	441	0.0026	223	0.0013
Emergency room visit	PM_{10}	5.48	441	0.0014	223	0.0007
Emergency room visit	SO_2	1.43	441	0.0004	223	0.0002
	Total			**0.0044**		**0.0022**
resp. symptoms days	NO_x	15820	8	0.0771	7.5	0.0695
resp. symptoms days	PM_{10}	2890	8	0.0141	7.5	0.0127
resp. symptoms days	SO_2	750	8	0.0037	7.5	0.0033
	Total			**0.0949**		**0.0855**
resp. hosp. Admission	NO_x	2.135	11654	0.0146	7870	0.0098
resp. hosp. Admission	PM_{10}	0.294	11654	0.0020	7870	0.0014
resp. hosp. Admission	SO_2	0.076	11654	0.0005	7870	0.0004
	Total			**0.0171**		**0.0116**
Restr. Activity days	NO_x	2030	58	0.0693	75	0.0891
Restr. Activity days	PM_{10}	1118	58	0.0381	75	0.0491
Restr. Activity days	SO_2	292	58	0.0100	75	0.0128
	Total			**0.1174**		**0.1510**
Radiation		0.02463	705	0.0000		
Lead health effects	Pb	1157	47	0.0319		
Mercury health effects	Hg	602	1	0.0003		
Survivable cancer	Toxics	0.000542	169816	0.0001	450000	0.0001
Morbidity total				**0.5922**		**0.4629**

Looking closer at the numbers chronic bronchitis, emergency room visits, resperatory symptom days and resperatory hospital admissions are all monetised higher in EXMOD than in EcoSense, while restricted activity days and asthma attacks are valued highest using EcoSense. This is shown in Figure 10.1.

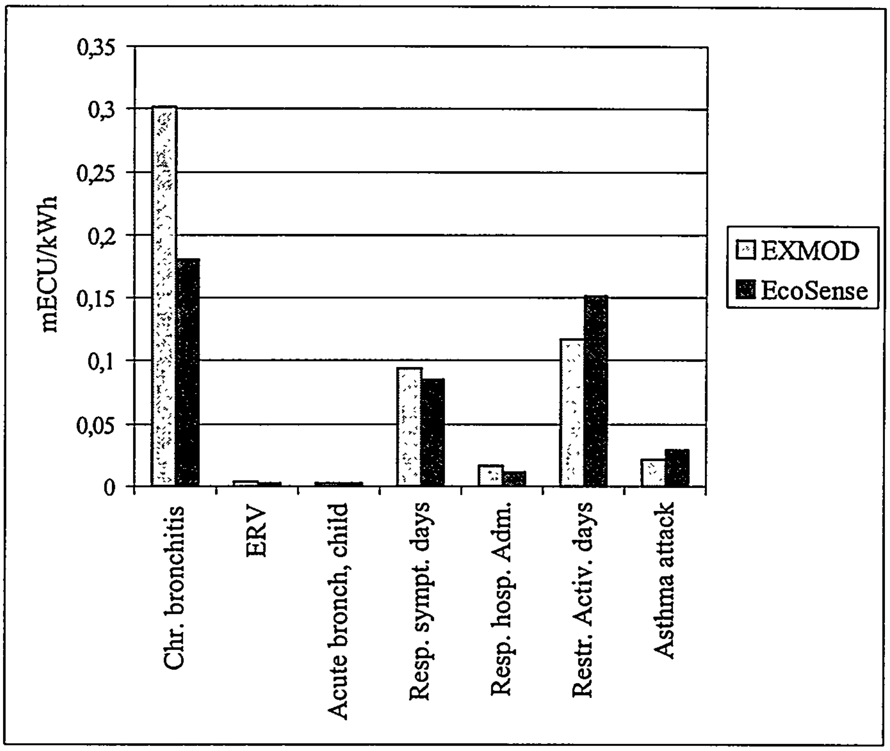

Figure 10.1 Morbidity damages calculated in EXMOD and EcoSense

10.2.2 Comparison of damage costs using the EcoSense model

Table 10.5 the morbidity impacts, the monetary values and the damage costs calculated in the EcoSense model for the same power plant. The monetary values used in EXMOD are shown in the table to the right and these values have been multiplied with the impacts calculated in EcoSense to give comparable results.

Table 10.5 Morbidity impacts using EcoSense

			EcoSense		EXMOD	
		Impacts	Mon. value (ECU)	Damage (mECU/kWh)	Mon. value (ECU)	Damage (mECU/kWh)
Congestive heart fail (> 65)	PM_{10}	0.03356	7870	0.0003		
Congestive heart fail (>65)	Nitrate	0.2529	7870	0.0020		
Congestive heart fail (>65)	Sulfate	0.2582	7870	0.0020		
	Total			**0.0043**		
Ischa. Heart disease (>65)	PM_{10}	0.03174	7870	0.0002		
Ischa. Heart disease (>65)	Nitrate	0.2392	7870	0.0019		
Ischa. Heart disease (>65)	Sulfate	0.2442	7870	0.0019		
	Total			**0.0040**		
Adults, Restr. Activity days	PM_{10}	198.4	75	0.0149	58	0.0115
Adults, Restr. Activity days	Nitrate	1495	75	0.1121	58	0.0867
Adults, Restr. Activity days	Sulfate	1522	75	0.1142	58	0.0883
	Total			**0.2412**		**0.1865**
Adults, Chronic bronchitis	PM_{10}	0.3897	105000	0.0409	174811	0.0681
Adults, Chronic bronchitis	Nitrate	2.937	105000	0.3084	174811	0.5134
Adults, Chronic bronchitis	Sulfate	2.858	105000	0.3001	174811	0.4996
	Total			**0.6494**		**1.0811**
Adults, Bronchodilator use	PM_{10}	45.35	37	0.0017	28	0.0013
Adults, Bronchodilator use	Nitrate	341.7	37	0.0126	28	0.0096
Adults, Bronchodilator use	Sulfate	348.2	37	0.0129	28	0.0097
	Total			**0.0272**		**0.0206**
Adults, Cough	PM_{10}	46.65	7	0.0003	8	0.0004
Adults, Cough	Nitrate	351.5	7	0.0025	8	0.0028
Adults, Cough	Sulfate	358.2	7	0.0025	8	0.0029
	Total			**0.0053**		**0.0061**
Adults, Low resp. symptom	PM_{10}	16.87	7.5	0.0001	8	0.0001
Adults, Low resp. symptom	Nitrate	127.1	7.5	0.0010	8	0.0011
Adults, Low resp. symptom	Sulfate	129.5	7.5	0.0010	8	0.0011
	Total			**0.0021**		**0.0023**
Child, Bronchodilator use	PM_{10}	9.084	37	0.0003	28	0.0003
Child, Bronchodilator use	Nitrate	68.45	37	0.0025	28	0.0019
Child, Bronchodilator use	Sulfate	69.76	37	0.0026	28	0.0020
	Total			**0.0054**		**0.0042**
Child, Cough	PM_{10}	15.64	7	0.0001	8	0.0001
Child, Cough	Nitrate	117.9	7	0.0008	8	0.0009
Child, Cough	Sulfate	120.1	7	0.0008	8	0.0010
	Total			**0.0017**		**0.0020**
Child, Low resp. symptom	PM_{10}	12.06	7.5	0.0001	8	0.0001
Child, Low resp. symptom	Nitrate	90.88	7.5	0.0007	8	0.0008
Child, Low resp. symptom	Sulfate	92.6	7.5	0.0007	8	0.0008
	Total			**0.0015**		**0.0017**
Child, Chronic cough	Nitrate	52.23	225	0.0118	225	0.0118
Child, Chronic cough	PM_{10}	6.932	225	0.0016	225	0.0016
Child, Chronic cough	Sulfate	53.33	225	0.0120	225	0.0120
	Total			**0.0254**		**0.0254**
Child, chronic Bronchitis	Nitrate	40.63	225	0.0091	225	0.0091
Child, chronic Bronchitis	PM_{10}	5.392	225	0.0012	225	0.0012
Child, chronic Bronchitis	Sulfate	41.48	225	0.0093	225	0.0093
	Total			**0.0196**		**0.0196**

Table 10.5 continued. Morbidity impacts using EcoSense

		Impacts	EcoSense Mon. value (ECU)	Damage (mECU/kWh)	EXMOD Mon. value (ECU)	Damage (mECU/kWh)
Cancer	Cd	1.48E-05	450000	0.0000	169816	0.0000
Cancer	Cr	0.001061	450000	0.0005	169816	0.0002
Cancer	As	2.41E-06	450000	0.0000	169816	0.0000
Cancer	Ni	9.64E-05	450000	0.0000	169816	0.0000
	Total			**0.0005**		**0.0002**
resp. hosp. Admission	PM_{10}	0.02888	7870	0.0002	11654	0.0003
resp. hosp. Admission	Nitrate	0.2176	7870	0.0017	11654	0.0025
resp. hosp. Admission	Sulfate	0.2224	7870	0.0018	11654	0.0026
	Total			**0.0037**		**0.0054**
ERV for COPD	PM_{10}	0.1005	223	0.0000	441	0.0000
ERV for COPD	Nitrate	0.757	223	0.0002	441	0.0003
ERV for COPD	Sulfate	0.7729	223	0.0002	441	0.0003
	Total			**0.0004**		**0.0006**
ERV for asthma	PM_{10}	0.09	223	0.0000	441	0.0000
ERV for asthma	Nitrate	0.6782	223	0.0002	441	0.0003
ERV for asthma	Sulfate	0.6924	223	0.0002	441	0.0003
	Total			**0.0004**		**0.0006**
hosp. Visits child. Croup	PM_{10}	0.406	223	0.0001	441	0.0002
hosp. Visits child. Croup	Nitrate	3.06	223	0.0007	441	0.0014
hosp. Visits child. Croup	Sulfate	3.124	223	0.0007	441	0.0014
	Total			**0.0015**		**0.0030**
Cerebrov. Hosp. Adm	PM_{10}	0.07032	7870	0.0006	11654	0.0008
Cerebrov. Hosp. Adm	Nitrate	0.5299	7870	0.0042	11654	0.0062
Cerebrov. Hosp. Adm	Sulfate	0.541	7870	0.0043	11654	0.0063
	Total			**0.0091**		**0.0133**
Morbidity total				**1.0026**		**1.3726**

Some assumptions must be made in order to compare the results from the two models. Bronchodilator usage for as well adults as children is not directly included in EXMOD. However, this must be regarded as an asthma attack in EXMOD with the monetary value of 28 ECU. Asthmatic cough is another impact not included in EXMOD, but must be included in acute respiratory symptoms in EXMOD with the monetary value of 8 ECU. Cases of chronic cough in EcoSense will be regarded as cases of acute bronchitis in EXMOD valued to 225 ECU both in EcoSense and EXMOD. As seen from the table there are no monetary values for congestive heart failure and ischaese heart disease in EXMOD.

Analysing the results from the two models the externalities calculated using the EXMOD monetisation values are 37% higher than using the EcoSense monetisation. This result corresponds to the result using the EXMOD model, applying that the monetary values used in EXMOD in generel are higher than the values used in EcoSense. The most dominating monetary value is for chronic bronchitis for adults, which results in a 66% higher damage in EXMOD than EcoSense.

10.2.3 Comparison of damage costs using the EXMOD model and the EcoSense model

The damage costs has been calculated for the same pulverised coal fired plant using the EXMOD model and the EcoSense model. As indicated above the damages are higher using the EXMOD values than using the EcoSense values. However, comparing the damage costs for the same plant, but using different models, results in higher damage costs using the EcoSense model than using the EXMOD model. This is shown Figure 10.2.

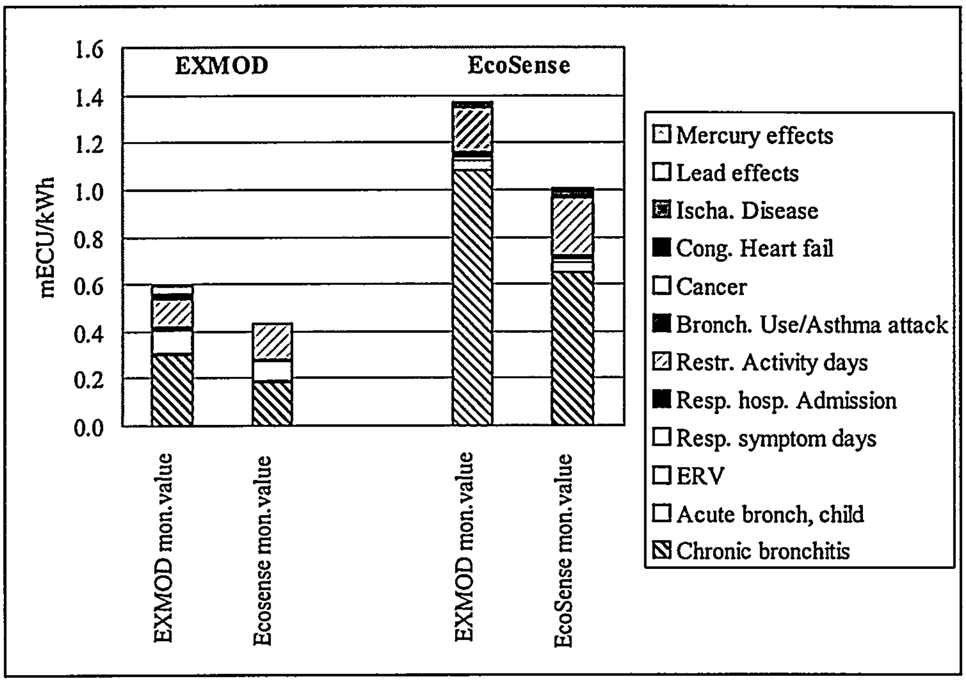

Figure 10.2 Damage costs calculated in EcoSense and EXMOD for the same power plant

The figure shows more than a doubling of the damage costs using EcoSense instead of EXMOD. Chronic bronchitis is the dominating impact in both models, accounting for above 50% of the damage costs. Also restricted activity days are important, having more effect in EcoSense than in EXMOD. Restricted symptoms days accounts for 16% of the damage costs using the EXMOD model, while it is negligible using the EcoSense model. Other impacts have smaller significance in both models.

Why are the damage costs different using the same monetary values in two different models, but for the same plant? One important parameter, not included in this analysis, may be the location of the plant. Using EXMOD the plant is situated in Capital District, which is a suburban site outside of Albany, while the same plant in EcoSense is situated in Roskilde, Denmark. There may be differences in the dispersion and impacts of the emissions in the two cases, because of differences in background levels of the emissions in the two locations with surroundings and because of differences in population size.

10.3 Analysis of impacts

The amount of impacts for the different categories is like the monetary values used an important factor, when analysing the external costs calculated from different models. Therefore the different morbidity impacts calculated for the same plant in as well EcoSense as EXMOD have been compared in the next three figures.

Figure 10.3 shows large differences in the amount of impacts for the two models. Especially the cases of children with acute bronchitis are much higher in EcoSense than in EXMOD. It seems unrealistic that the amount of children in the population should be much larger in Europe than in US. More realistic is that there are differences in the dose-response functions used to define a case of children with acute bronchitis. Regarding Figure 10.2 cases of children with acute bronchitis are also more significant in EcoSense than in the EXMOD model.

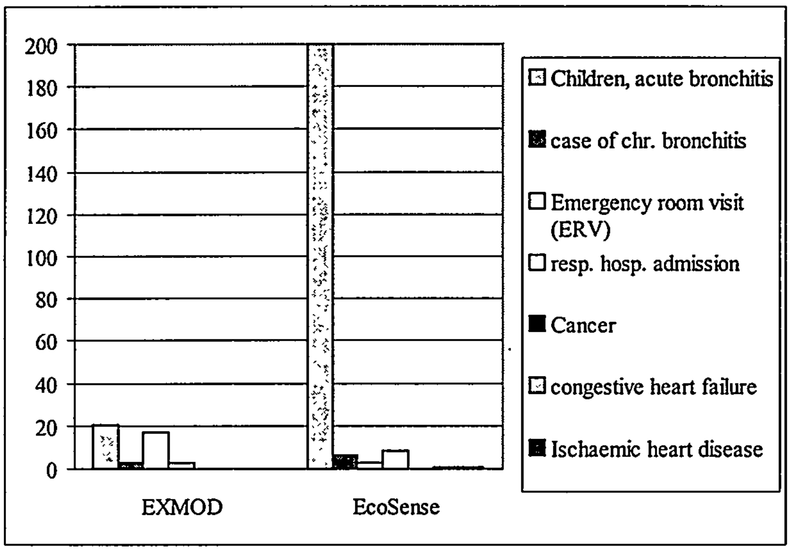

Figure 10.3 Cases of impacts calculated in EXMOD and EcoSense

Figure 10.4 shows the same impacts as Figure 10.3, but the cases of children with acute bronchitis have been excluded from the figure. This figure also shows large differences in the cases of impacts, however, the number of cases are much smaller. Comparing the results with Figure 10.2 shows that although the number of cases of chronic bronchitis is small, this impact is the most dominating impact in the external costs. The reason for this is the large monetary value of this impact. The damage costs of chronic bronchitis in Figure 10.2 are larger in EcoSense than in EXMOD. This is a result of more cases of chronic bronchitis using EcoSense, although the monetary value are larger in the EXMOD model.

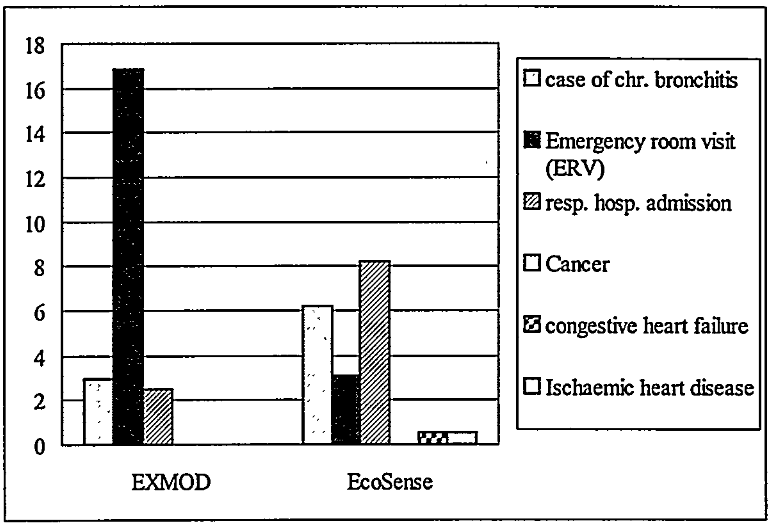

Figure 10.4 Cases of impacts calculated in EXMOD and EcoSense

Figure 10.5 shows a very large difference in the cases of respiratory symptoms days in the two models. Using the EXMOD model the numbers of respiratory symptoms days are 19460, while using EcoSense the number of cases is 1479. This is visible in Figure 10.2, where respiratory symptoms days are important in EXMOD, but not visible in EcoSense. Taking the large number of cases into consideration the damage costs related to respiratory symptoms days are small due to a low monetary value.

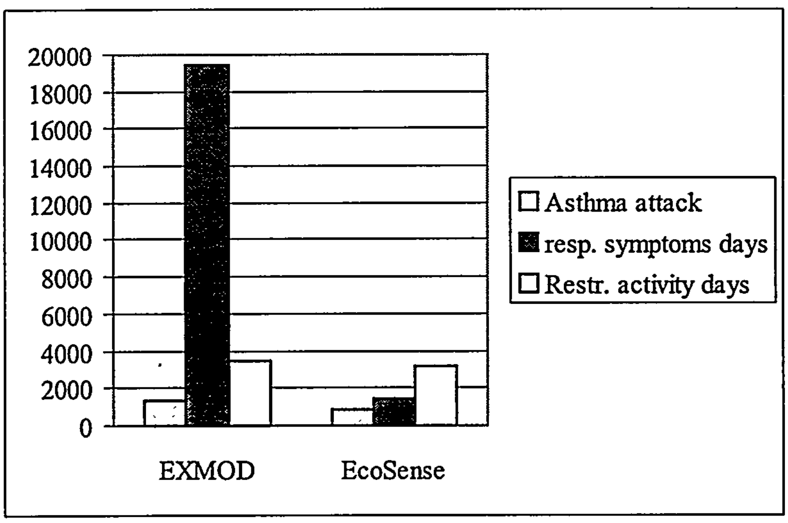

Figure 10.5 Cases of impacts calculated in EXMOD and EcoSense

Figure 10.6 shows the importance of the difference emissions in the two models. In EcoSense SO_2 and NO_x have nearly the same weight, while particulates have much smaller weight on the impacts. Comparing this with the weighing in EXMOD, NO_x are the most dominating, followed by particulates, while SO_2 has a small effect. The reason for these different dispersions may be the background level of the emissions in Europe and US.

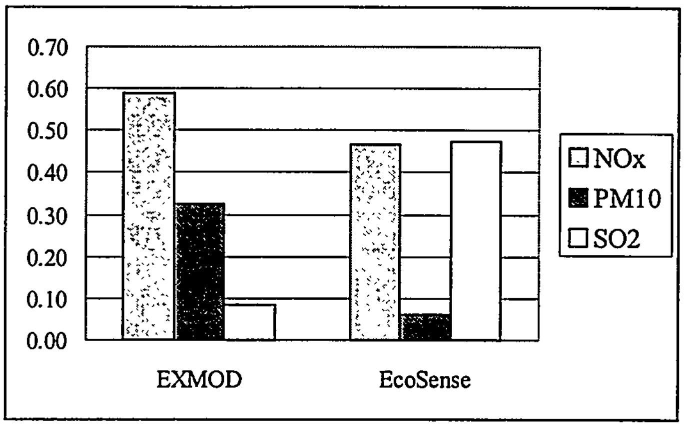

Figure 10.6 The weighing of NO_x, particulates and SO_2 on the impacts in the two models

The air quality models predict the level of the emissions in different locations influenced by the emissions from the plant. This level is called the delta concentration. The delta concentration is the only factor that is calculated in the models and is different for the involved emissions. For each impact the delta concentration times the population is multiplied by a dose-response function. This is included in the models, but may as well be calculated manually, having estimated the delta concentration in the computer models. The difference in delta concentration and population used in the two models is a result of different locations of the same plant, and will result in different amount of impacts for the two locations.

For PM_{10} the delta concentration times the population has been found to be a factor 1.75 higher in EXMOD than in EcoSense. This means that the impacts of PM_{10} estimated in EXMOD should be 1.75 larger than the same impacts estimated in EcoSense. However, this is only the case when using the same linear dose-response functions in the two models.

As an example restricted activity days are estimated in EcoSense by the following function:

$$RAD_{eco} = 25 * \text{Delta Concentration} * \text{Population} * \text{adults}/1000$$

where adults are defined as 57 % of the total population.

In EXMOD the function is as follows:

$$RAD_{ex} = 58.4 * \text{Delta Concentration} * \text{Population} * \text{adults}/1000$$

Here adults are defined as 83 % of the total population.

Giving that Delta Concentration * Population is 1.75 larger using EXMOD than using EcoSense and merging the two functions results in the following:

$$RAD_{eco} = 0.168 * RAD_{ex}$$

The same calculations can be made for other impacts as far as the dose-response functions are linear.

It must be noted that the delta concentration depends on the emission, meaning that the impacts are 1.75 larger using EXMOD than EcoSense only related to PM_{10} emission. For other emissions like nitrate and sulphate the situation is different.

10.4 Conclusion

External costs for power generation technologies may be assessed using different approaches and therefore the external costs may differ for the same technology depending of the approach used. In this paper the same approach – the bottom-up approach – has been used, but with two different models. The models are in principle built up in the same way with air dispersion models and dose-response functions for the calculation of impacts. These impacts are multiplied with monetary values to calculate the external costs.

Although the models seems more or less similar the resulting external costs are the five times larger in the ExternE study using the EcoSense model than in the New York study using the EXMOD model for the same power plant. First of all this is a result of CO_2, which is included in ExternE, but not in the New York study. However, excluding CO_2 the results still are three times as high in the ExternE study.

When the results are compared, it becomes clear that the impacts included in the studies as well as the monetary values and the dose-response functions used in the models to calculate the impacts are quite important. However, another important issue is the location of the plant, as differences in population size and differences in background levels of the emissions are quite important parameters, when utilising dispersion models for externality estimations.

Comparing the results has shown the importance of as well the monetary values used in the models as the dose-response functions used to calculate the impacts.

11 Comparison of results from ExternE and the TER study

A comparison of the impacts and damage costs related to air emissions has been made for the two studies. The ExternE study uses the EcoSense model for a pulverised coal-fired plant with a capacity of 300 MW. This is compared to the results for the rural and the Metropolitan Fringe scenario in the TER study as well as the urban scenario. The external costs for the three scenarios are estimated in $/tonnes pollutant. Multiplying these results with the emissions from the 300 MW plant used in the ExternE study makes the estimated external costs comparable. The results are estimated in mECU/kWh, 1995 level. However, using this methodology the results from the two studies are not completely comparable, as the scenarios in the TER study are results of plants with different stack heights, while the ExternE study only refers to a plant with a stack height of 235 m. The dispersion of the emissions is therefore in different heights.

In the TER study the plant in the rural scenario is located in an agricultural area in Minnesota, while the same plant in the Metropolitan Fringe scenario is located west of Minneapolis/St. Paul close to metropolitan areas. In the urban scenario the plant is located in St. Paul. In ExternE the plant is located in Roskilde, Denmark.

Table 11.1 Central estimates of external costs for a coal-fired plant

Externalities	Rural scenario (mECU/kWh)	Metropolitan Fr. scenario (mECU/kWh)	Urban scenario (mECU/kWh)
Human health	0.06	0.23	0.52
Mortality	*0.025*	*0.079*	*0.172*
Morbidity	*0.039*	*0.150*	*0.352*
Crops	0.01	0.04	0.16
Materials	0.006	0.02	0.07
Other impacts	0.002	0.005	0.02
Greenhouse gas effect	0	0	0
Total	0.08	0.30	0.77

Table 11.1 shows the importance of the location of the plant analysed. The external costs are highest in the urban scenario, and only about one-tenth in the rural scenario, which is a result of the very low population density in Minnesota compared to the population density in the urban scenario. The metropolitan Fringe scenario lies between the two others scenarios concerning population density.

The urban scenario has been selected for further analysis, as this scenario has the largest population density, and is most comparable to ExternE. In Table 11.2 this scenario is compared to the ExternE study.

Table 11.2 Central estimates of external costs for a coal-fired plant

Externalities	The TER study Urban scenario (mECU/kWh)	ExternE (mECU/kWh)
Human health	0.52	9.27
Mortality	*0.172*	*7.97 (32.46)*
Morbidity	*0.352*	*1.30*
Crops	0.16	0.134
Materials	0.07	0.22
Other impacts	0.02	0
Greenhouse gas effect	0	6.10
Total	0.77	15.72 (40.21)

On comparing the externalities for the same power plant estimated in the two studies, we see that the externalities are 20 times higher in the ExternE study than in the TER study. The difference in the external costs in the two studies reflects differences in impacts, differences in monetary values included in the two studies and especially differences in location of the plants. This is obvious in the difference in the three scenarios in the TER study, illustrating higher externalities in urban and metropolitan areas than in rural areas. Another very important factor is that the TER study has limited the area of dispersion only to cover the states Minnesota, western Wisconsin and south-eastern South Dakota, being an area about 10 times smaller than the area covered by EcoSense.

The differences in the estimates that are most apparent are the external costs of human health. The external costs of mortality are about 50 times as high in ExternE as in the TER study. EcoSense normally uses the YOLL approach; the figures in brackets are based on the VSL approach. As well mortality as morbidity is much higher in EcoSense than in the TER study. In EcoSense mortality includes as well chronic as acute mortality, while the TER study only covers acute mortality. Excluding chronic mortality the estimate for human health becomes 21 times higher in EcoSense than in the TER study.

Another important parameter is the greenhouse gas effect. The greenhouse gas effect is not included in the TER study, but in the ExternE study four different values of CO_2 have been estimated. In the above table, a value of 18 ECU/t CO_2 has been used. Including the global warming effect as well as chronic mortality in the TER study results a 25% higher estimate in the ExternE study than in the TER study.

Other impacts are impacts like visibility loss, which is included in the TER model, but not in the EcoSense model. Human health is the dominant impact in both models, and the reasons for the differences in the estimates of the effect on human health in the two studies will be explained below.

11.1 Mortality

The mortality impacts and damages have been calculated for a pulverised coal fired plant using the EcoSense model. For comparison the damages have been calculated using the VSL value. EcoSense normally uses the YOLL approach resulting in much smaller external costs for mortality. The damages calculated using the monetary value from the TER study for these impacts are included in the table, resulting in smaller damage costs.

Table 11.3 Mortality impacts using EcoSense, central estimate

		EcoSense			TER	Eco/TER
		Impacts	Mon value (ECU)	Damage (mECU/kWh)	Mon value (ECU)	Damage (mECU/kWh)
Chronic mortality	PM_{10}	0.5726	3.1 mio	1.78	2.815 mio	1.61
	Nitrate	4.3		13.4		12.10
	Sulfate	4.4		13.6		12.39
	Total	**9.27**		**28.78**		**26.10**
Acute mortality	SO_2	1.198	3.1 mio	3.71	2.815 mio	3.37
Total		**1.7706**		**32.49**		**29.47**

The mortality impacts and the damages calculated in the TER study are shown in Table 11.4. In the TER study only acute mortality is included as a result of particulate emission.

Table 11.4 Mortality impacts in the TER study, central estimate

		Impacts	Mon value (ECU)	Damage (mECU/kWh)
Acute mortality	PM	0.06	2.872 mio	0.172
Total		**0.06**	**2.872 mio**	**0.172**

Comparing Table 11.3 and Table 11.4 the external costs of mortality are 190 times as high in ExternE as in the TER study, when using the VSL approach (using the YOLL approach for EcoSense results in this case in 7.97 mECU/kWh). However, for comparison mortality has been estimated using the VSL approach for both models.

Comparing the results the most obvious reason for the large difference in mortality impacts for the two models beside the monetary value used, is that chronic as well as acute mortality is included in EcoSense, while only acute mortality is included in the TER study.

The impacts estimated in EcoSense for acute mortality are about 21 times as high as those estimated in the TER study. A reason for the large difference is that the TER study affects a much smaller area than EcoSense. Another important difference is that acute mortality impacts in EcoSense is assigned to SO_2, while in the TER study the impacts are assigned to PM.

11.2 Morbidity

In order to compare the externalities related to morbidity, the morbidity impacts, monetary values and damage costs for the two studies have been compared.

The damage costs have been calculated for the same pulverised coal-fired plant, using the TER study and the EcoSense model. On comparing the damage costs for the same plant, we note that there are higher damage costs when the EcoSense model is used than when the TER model is used. This is shown in Figure 1. The first two columns in the figure represent the external costs calculated in the TER study, the first column with monetary values from TER, the second with monetary values from EcoSense. The last two columns represent the external costs calculated in EcoSense, the first column with monetary values from TER, the second with monetary values from EcoSense.

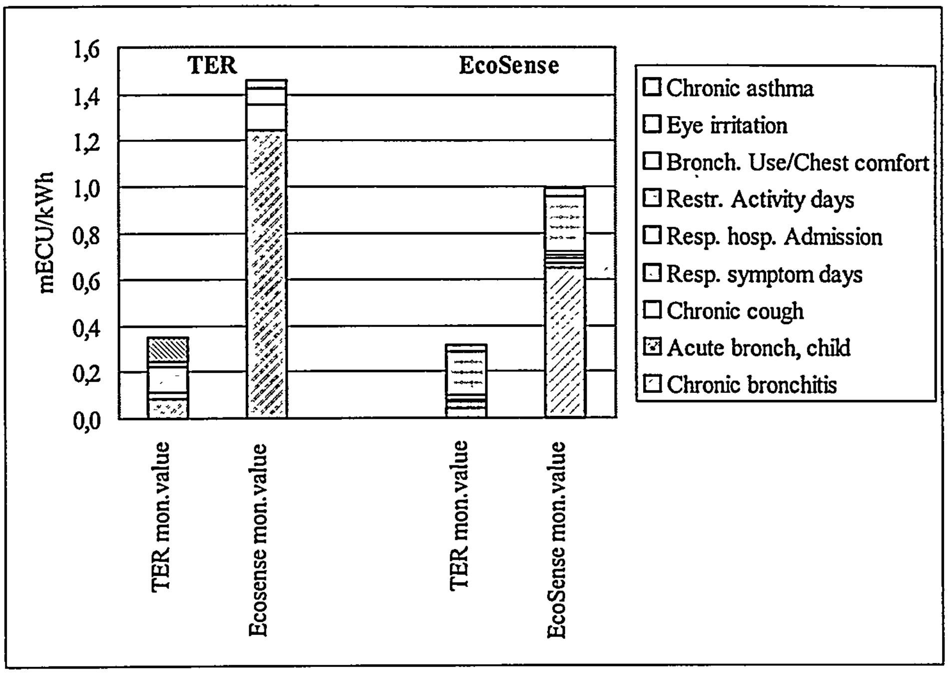

Figure 11.1 Damage costs for morbidity calculated in EcoSense and TER for the same power plant, central estimate

The figure shows about three times higher damage costs for morbidity using EcoSense rather than TER. Chronic bronchitis is the dominant impact in EcoSense, accounting for more than 50% of the damage costs, while in the TER study it accounts for less than a third of the costs. Restricted activity days are also important, in EcoSense, but not visible in TER. Restricted symptom days account for more than one third of the damage costs using the TER model, while they are negligible using the EcoSense model. Chronic cough has small effect in both models, but using the monetary value from EcoSense in the TER model results in a visible effect. Eye irritation accounts for nearly one third of the damage costs in the TER study, while this impact not is included in EcoSense. Other impacts have lesser significance in both models.

Analysing the results from the EcoSense model the externalities are three times higher using the EcoSense monetisation values than using the TER monetisation. This result corresponds to the result when using the TER model, applying that the monetary values used in TER in general are lower than the values used in EcoSense. However, when the same monetary values for the two models are used, much higher morbidity costs are encountered with the TER model.

11.3 Important parameter for different external costs

Four parameters have importance, when comparing the external costs for the two studies:

- Difference in delta concentration and population for US and Europe
- Difference in impacts
- Different dose-response functions
- Different monetary values

The four parameters are depending on each other. However, in the following the importance of the parameters has been tried to be explained individually.

11.3.1 Difference in delta concentration and population for the US and Europe

The air quality models predict the level of the emissions in different locations influenced by the emissions from the plant. This level is called the delta concentration. The delta concentration is the only factor that is calculated in the models and is different for the involved emissions. For each impact the delta concentration times the population is multiplied by a dose-response function. This is included in the EcoSense model, but may as well be calculated manually, having estimated the delta concentration in the computer models. This is the case in the TER study. The difference in delta concentration and population used in the two models is a result of different locations of the same plant, and will result in different amount of impacts for the two locations.

A very important factor in the comparison of the functions is that the TER study is limited to the states Minnesota, western Wisconsin and south-eastern South Dakota.

Figure 11.2 shows the importance of the difference in emissions in the two models. In EcoSense the secondary emissions sulphate and nitrate have nearly the same weight, while PM_{10} has much smaller weight on the impacts. Comparing this with the weighting factors in TER, nitrate is the most dominant, followed by PM_{10}, while sulphate only has a small effect. In EcoSense nitrate, sulphate and PM_{10} has the same effect at all the morbidity impacts, while in TER each impact is a result of only one emission.

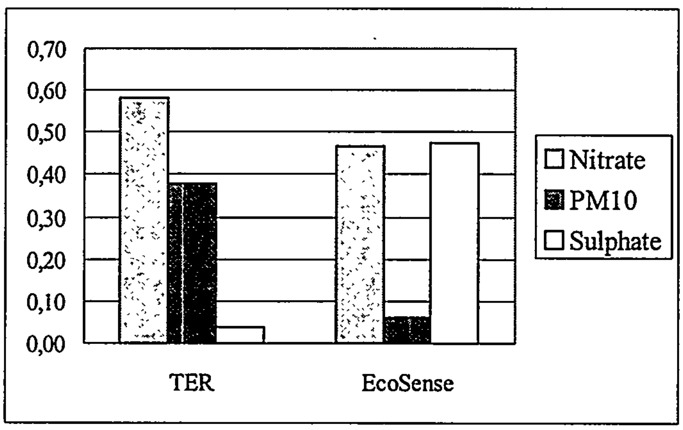

Figure 11.2 The relative weighting factors of nitrate, PM_{10} and sulphate on the impacts in the two models

11.3.2 Difference in impacts

The impacts included in two studies may differ, which will affect the total external costs estimated in the studies. For mortality, as mentioned, the TER study includes only acute mortality, while EcoSense include as well acute as chronic mortality. This difference in impacts mean a factor of 30 more impacts in EcoSense as in the TER study, and a difference of 190 times larger externality costs in EcoSense as in TER concerning mortality. Also in morbidity impacts there are differences between the two models. Table 11.5 shows the morbidity impacts estimated in EcoSense and in TER.

The table illustrates that it is necessary to make some assumptions in order to compare the results from the two models, as the impacts differ rather much. Only two of the impacts are directly comparable in the two studies, being chronic cough and low respiratory symptoms for adults. Cough days in TER is compared to restricted activity days in EcoSense, being days with cough, headache etc. but still able to go to work. Chronic bronchitis for adults is directly comparable in the two models, although it in TER is called emphysema. Bronchodilator usage does not exist in TER, but is considered to be days with chest discomfort.

Acute bronchitis for children in TER is similar to chronic bronchitis in EcoSense. The amount of impacts is twelve times higher in EcoSense than in TER, which apparently is a result of differences in delta concentrations and size of population. Upper respiratory symptoms for adults in TER are compared to asthmatic cough for adults in EcoSense.

Table 11.5 Morbidity impacts in EcoSense and TER, central estimate

EcoSense	Impacts	TER	Impacts
Congestive heart fail (> 65)	0.54		
Ischa. Heart disease (>65)	0.51		
Restricted activity days	3215	Cough days, children	53
Chronic bronchitis, adults	6.19	Emphysema etc., adult	12
Chronic Bronchitis, child	88	Acute bronchitis, children	7
Bronchodilator use, adults	735	Chest discomfort, all	806
Bronchodilator use, child	147		
Asthmatic cough, adults	756	Up. resp. symptoms, adults	767
Asthmatic cough, child	254		
Low resp. symptom, adults	273	Low resp symptoms, adults	2213
Low resp. symptom, child	195		
Chronic cough, children	112	Chronic cough, children	483
Resperatory hosp. adm.	0.47		
Cerebrov. Hosp. adm.	1.14		
hosp. Visits child. Croup	6.6		
ERV for COPD	1.6		
ERV for asthma	1.5		
		Chronic asthma, children	17
		Eye irritation, all	8623

Chronis asthma and eye irritation are impacts only included in the TER study, while congestive heart failure (> 65) and ischa. heart disease (>65) is represented only in EcoSense.

11.3.3 Different dose-response functions

Looking at the above mentioned assumptions it is obvious that some of the dose-response functions that are compared differ, resulting in differences in amount of impacts. The dose-response functions in Ecosense are all linear, while in the TER study many of the dose-response functions are exponential. Some of the morbidity impacts calculated for the same plant in EcoSense as well as TER have been compared in the next figure.

Figure 11.3 shows the very large difference in the cases of restricted activity days, lower respiratory symptoms as well as chronic cough in the two models. This is also visible in Figure 11.1, where restricted activity days are important in EcoSense, but not visible in TER. In the same way respiratory symptoms are important in TER, but not visible in EcoSense.

Restricted activity days in EcoSense have been compared to cough days in TER, which is not directly comparable. Cough days are only related to children, being a smaller amount of the population. Lower respiratory symptoms and chronic cough are impacts directly comparable in the two models. However, both impacts are much larger in TER, although TER covers only a small population. The reason for the large difference in these impacts in the two models is, that the dose-response functions used to define the impacts differ.

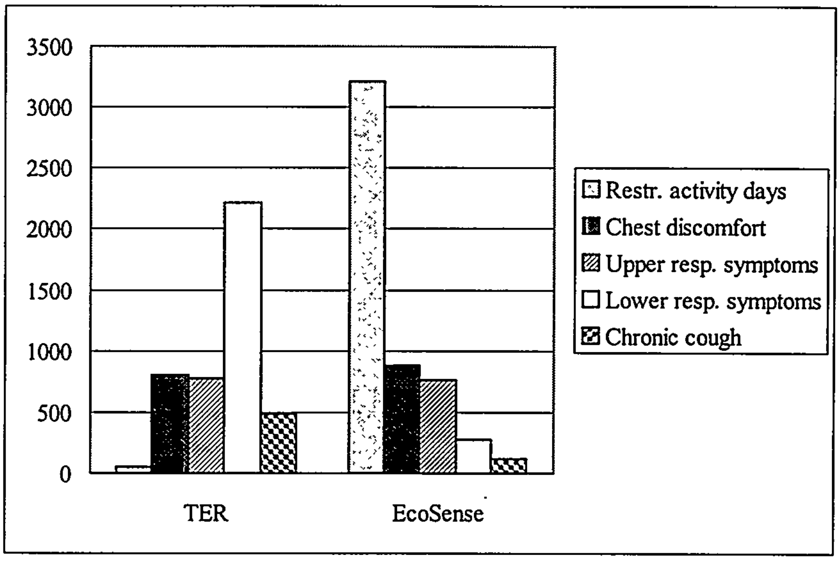

Figure 11.3 Cases of impacts calculated in TER and EcoSense

11.3.4 Different monetary values

As illustrated in Figure 11.1 the monetary values used is an important factor, when analysing the external costs calculated from different models. Comparing the morbidity results in Figure 11.1 on a superior level using the TER model the total damage costs caused by morbidity are only one fourth using the TER monetary values instead of using the values from EcoSense. This shows the importance of considerations concerning the monetary values used.

Figure 11.4 shows the external costs, which are estimated for mortality impacts in the TER study, using monetary values of as well TER as EcoSense. Chronic bronchitis is monetised much higher in EcoSense than in the TER study. Looking at the other impacts chronic cough and bronchodilator usage are monetised higher in EcoSense than in TER, while respiratory symptom days are valued highest using TER.

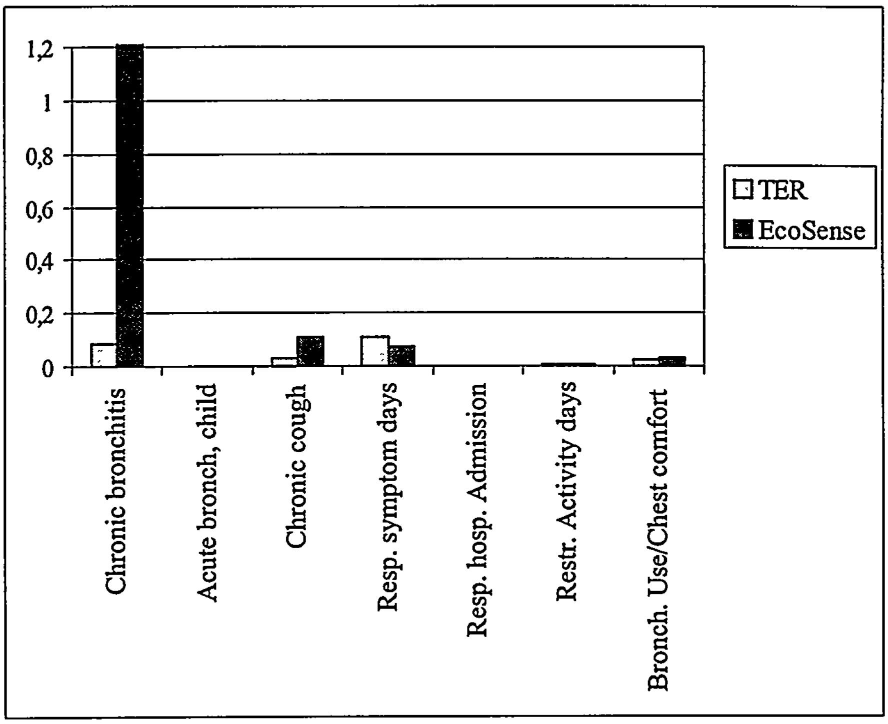

Figure 11.4 Morbidity damages calculated in TER using monetary values of TER and EcoSense

The above paragraphs have demonstrated the importance of the delta concentration and population as well as the difference in impacts included, the dose-response functions used and finally the use of different monetary values. Although the parameters have been explained separately, the tables and figures have shown that the parameters influence each other.

11.4 Conclusion

In this chapter the same approach – the bottom-up approach – has been used, but with two different models. The EcoSense model is built up with air dispersion models and dose-response functions for the calculation of impacts. These impacts are multiplied with monetary values to calculate the external costs. The TER model only consists of an air dispersion model, while dose-response functions and monetary values are calculated separately. Anyhow the models are comparable, but the resulting external costs are 20 times larger in the ExternE study using the EcoSense model than in the TER study for the same power plant. It is here important to note, that the TER study only covers the three states Minnesota, western Wisconsin and south-eastern South Dakota with a population of about 10 mio. people, while EcoSense covers a population of 600 mio. people.

When the results are compared, it becomes clear that the impacts included in the studies as well as the monetary values and the dose-response functions used in the models to calculate the impacts are quite important. However, the most important issue in the comparison of the results from the TER study with the ExternE study is the limiting of the TER study, which means large differences in population size, and therefore differences in amount of impacts.

12 Conclusion

The report has pointed out a number of those parameters, which are important to consider when externalities estimated for the same fuel cycle are compared in different studies. Some studies transfer dose-response functions and monetisation values from other studies. It must be considered carefully for each of the functions if it is possible to use functions from other studies, or if it is necessary to develop a function for a new region.

Four parameters have shown to be very important, when comparing external costs estimated in different studies, although the studies are based on the same approach:

- Difference in impacts
- Different monetary values
- Different dose-response functions
- Difference in delta concentration and population for the regions involved

The importance of these parameters is shown in Figure 12.1, where the human health effects estimated in EcoSense and EXMOD are compared. EXMOD starts with a central value of 2.84 mECU/kWh, while EcoSense starts at a value of 15.72 mECU/kWh.

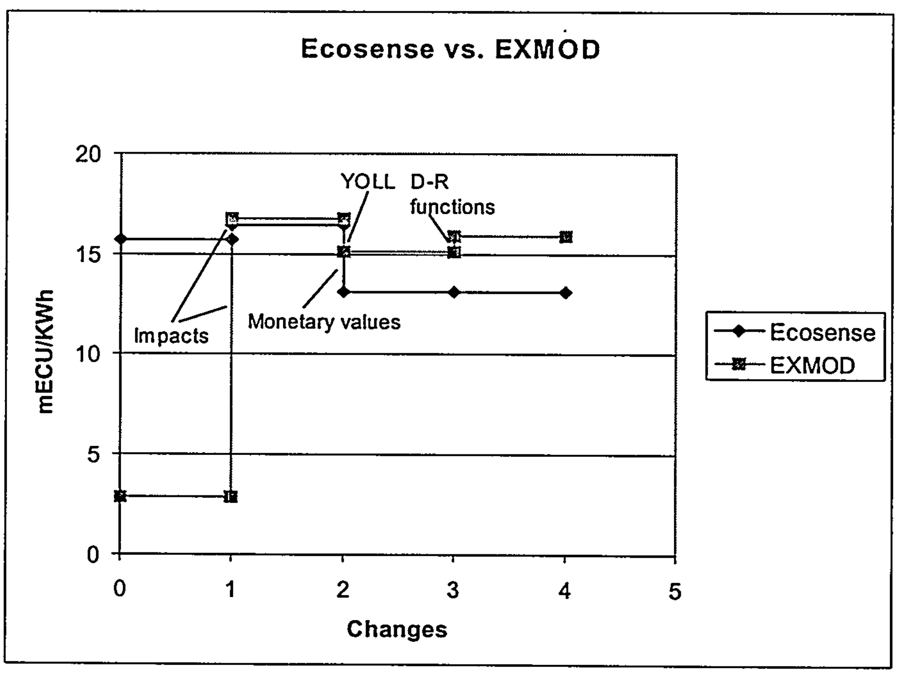

Figure 12.1 Differences in estimates of the effect on human health

Difference in impacts not included in either EXMOD or EcoSense makes the first jump in the figure. Greenhouse gasses are not included in EXMOD; including the value of this impact from EcoSense makes the external costs rise. In the case of EcoSense ozone impacts are not included.

The monetary values used in the two models differ also in some cases. One important factor here is the estimation of mortality using YOLL instead of VSL in EXMOD, which lowers the external costs for EXMOD. Using the other monetary values from EXMOD in EcoSense lowers the EcoSense value, and the EXMOD values become higher than the EcoSense values. Finally, there are differences in the dose-response functions included in the two models, which is shown in the last part of the figure. However, these differences are small compared to the other differences.

Having adjusted for the above-mentioned parameters there is a difference of 3 mECU/kWh in the two estimates. Most of this difference may be attributed to the different locations of the plants, which affect population density and background level of emissions.

As illustrated here, difference in those four parameters may result in large differences in the external costs for the energy technologies analysed. It is therefore quite important, when politicians use externalities to assess the importance of different kinds of energy technologies, that they use external costs for the technologies based on the same approach calculating the same impacts and using same monetary values and dose-response functions. This is also the case, when externalities are used by the electricity utilities to choose between different technologies in capacity building. Else the comparison of the technologies may be based on wrong assumptions.

13 References

Abbey D.E., Lebowitz M.D., Mills P.K., Petersen F.F., Lawrence Beeson W. and Burchette R.J. (1995) *Long-term ambient concentrations of particulates and oxidants and development of chronic disease in a cohort of nonsmoking California residents.* Inhalation Toxicology 7, 19-34.

Bates D.V., Baker-Anderson M. and Sizto R. (1990), *Asthma attack periodicity: A study of hospital emergency visits in Vancouver,* Environ Res 51, 51-70.

Bhattacharyva, S.C. (1997), *An estimation of environmental costs of coal-based thermal power generation in India.*

CEC, (1995a), Commission of the European Communities Joule Programme. *ExternE: Externalities of Energy - Vol. 1 - Summary,* EUR 16520.

CEC, (1995b), Commission of the European Communities Joule Programme. *ExternE: Externalities of Energy - Vol. 2 - Methodology,* EUR 16521.

CEC, (1995c), Commission of the European Communities Joule Programme. *ExternE: Externalities of Energy - Vol. 3 - Coal and Lignite,* EUR 16522.

CEC, (1995d), Commission of the European Communities Joule Programme. *ExternE: Externalities of Energy - Vol. 4 - Oil and Gas,* EUR 16523.

CEC, (1995e), Commission of the European Communities Joule Programme. *ExternE: Externalities of Energy - Vol. 5 - Nuclear,* EUR 16524.

CEC, (1995f), Commission of the European Communities Joule Programme. *ExternE: Externalities of Energy - Vol. 6 - Wind and Hydro,* EUR 16525.

Dockery, D.W., Speizer, F.E., Stram, D.O., Ware, J.H., Spengler, J.D. and Ferries, B.G. (1989), *Effects of inhalable particles on respiratory health of children,* Am Rev Respir Dis 139, 587-594.

ETSU (1994), *Full Fuel Cycle Study on Power Generation Schemes, incorporating the Capture and Disposal of Carbon Dioxide,* Volumes 1 to 5.

European Commission (1995*), External Costs of Energy,* DGXII, Luxembourg.

Hohmeyer, O. (1988), *Social costs of energy consumption,* Springer Verlag, Berlin.

IEA coal research (1996), *Externalities and coal-fired power generation.*

Krupnick, A.J. and Cropper, M.L. (1992), *The effect of information on Health Risk Valuations,* Journal of risk and Uncertainty, 5 (1), pp.29-48

Krupnick A.J., Harrington W., Ostro B. (1990*), Ambient ozone and acute health effects: Evidence from daily data,* J. Environ Econ Manage 18, 1-18.

Navrud, S. and Pruckner, G.J., (1997), *Environmental Valuation – To Use or Not to Use? A comparative study for the United States and Europe*, In: Environmental and Resource Economics, 10; 1-26.

Oak Ridge National Laboratory (1992), *U.S.-EC fuel cycle Study*: Background Document to the Approach and Issues.

Ostro B.D. (1987), *Air pollution and morbidity revisited: A specification test,* J Environ Econ Manage 14, 87-98.

Ostro B.D. and Rothschild S. (1991), *Air pollution and acute respiratory morbidity: An observational study of multiple pollutants,* Environ Res 50, 238-247.

Ott, W. (1997), *External Costs and External Price Addings in the Swiss Energy Sector,* ECONCEPT, Zürich, Switzerland. In Social Costs and Sustainability.

Ottinger, R.L., D.R. Wooley, N.A. Robinson, D.R. Hodas, S.E. Babb (1991), *Environmental costs of electricity*, Oceana Publications Inc., New York.

Pace (1990), *Environmental costs of electricity,* Pace University Centre for Environmental Legal Studies. Prepared for the New York State Energy Research and Development Authority and US Department of Energy.

Pearce, D., Bann, C. and Georgiu, S. (1992), *The social costs of fuel cycles,* A report for the UK Department of Trade and Industry. HMSO, London.

Pope C.A. III, Thun M.J., Namboodiri M.M., Dockery D.W., Evans J.S., Speizer F.E. and Heath C.W. Jr. (1995), *Particulate air pollution as predictor of mortality in a prospective study of US adults.* Am J Resp Crit Care Med 151: 669-674.

Rowe, R., Lang, C., Chestnut, L., Latimer, D., Rae, D., Bernow, S., and White, D. (1995), *The New York Electricity Externality Study.* Oceana Publications: Dobbs Ferry, NY.

Russell, Lee (1997), *Externalities studies: Why are the numbers different?* Oak Ridge National Laboratory, In Social Costs and Sustainability.

Schleisner, L. and Nielsen, P.S. (1997), *External Costs related to Power Production Technologies ExternE National Implementation for Denmark, App.1*, Risø National Laboratory.

Schleisner, L. and Nielsen, P.S. (1997), *External Costs related to Power Production Technologies ExternE National Implementation for Denmark,* Risø National Laboratory.

Schwartz J. (1993). *Particulate air pollution and chronic respiratory disease.* Environ Res 62, 7-13.

Schwartz J., Spix C., Wichmann H.E. and Malin E. (1991), *Air pollution and acute respiratory illness in five German communities*, Environ Res 56, 1-14.

Sunyer J., Saez M., Murillo C., Castellsague J., Martinez F. and Antó J.M. (1993), *Air pollution and emergency room admissions for chronic obstructive pulmonary disease: A 5-year study,* Am J Epid 137, 701-705.

Triangle Economic Research, (1995), *Assessing Environmental Externality Costs for Electricity Generation.*

Viscusi, W.K., Magat, W.A. and Forrest, A. (1988), *Altruistic and Private Valuations of Risk Reductions*, Journal of Policy Analysis and Management, 7 (2), pp.227-245.

Appendix

The appendix contains the basis of the external costs estimated in the three studies:

- ExternE National Implementation
- The New York Electricity Externality Study
- The Northern States Power Company Study

Table 0.1 shows the impacts and damages calculated in EcoSense, compared to the damages for the same impacts using EXMOD and TER monetary values.

Table 0.2 shows the impacts and damages calculated in EXMOD, compared to damages for the same impacts using EcoSense monetary values.

Table 0.3 – Table 0.5 shows the impacts and damages calculated in the TER study for respectively the rural scenario, the metropolitan scenario and the urban scenario.

Table 0.6 shows the impacts and damages calculated in TER, compared to damages for the same impacts using EcoSense monetary values.

Table 0.1 Impacts and damages calculated in EcoSense, compared to damages using EXMOD and TER monetary values

			EcoSense			EXMOD		TER	
		Morbidity	Monetary value	Central impacts	Damages	Monetary value	Damages	Monetary Value	Damages
Pollutant	ReceptorGroup	Impact	ECU		mECU/ kWh	ECU	mECU/ kWh	ECU	mECU/ kWh
PM_{10}	above_65_yrs	congestive heart failure	7870	0.03356	0.0003				
Nit	above_65_yrs	congestive heart failure	7870	0.2529	0.0020				
Sul	above_65_yrs	congestive heart failure	7870	0.2582	0.0020				
				0.54466	**0.0043**				
PM_{10}	above_65_yrs	Ischaemic heart disease	7870	0.03174	0.0002				
Nit	above_65_yrs	Ischaemic heart disease	7870	0.2392	0.0019				
Sul	above_65_yrs	Ischaemic heart disease	7870	0.2442	0.0019				
				0.51514	**0.0041**				
PM_{10}	adults	Restr. activity days	75	198.4	0.0149	58	0.0115	59	0.0117
Nit	adults	Restr. activity days	75	1495	0.1121	58	0.0867	59	0.0882
Sul	adults	Restr. activity days	75	1522	0.1142	58	0.0883	59	0.0898
				3215.4	**0.2412**		**0.1865**		**0.1897**
PM_{10}	adults	chronic bronchitis	105000	0.3897	0.0409	174811	0.0681	6960	0.0027
Nit	adults	chronic bronchitis	105000	2.937	0.3084	174811	0.5134	6960	0.0204
Sul	adults	chronic bronchitis	105000	2.858	0.3001	174811	0.4996	6960	0.0199
				6.1847	**0.6494**		**1.0812**		**0.0430**

			EcoSense			EXMOD		TER	
		Morbidity	Monetary value	Central impacts	Damages	Monetary value	Damages	Monetary Value	Damages
Pollutant	ReceptorGroup	Impact	ECU		mECU/ kWh	ECU	mECU/ kWh	ECU	mECU/ kWh
PM_{10}	asthma_adults	Bronchodilator usage	37	45.35	0.0017	28	0.0013	27	0.0012
Nit	asthma_adults	Bronchodilator usage	37	341.7	0.0126	28	0.0096	27	0.0092
Sul	asthma_adults	Bronchodilator usage	37	348.2	0.0129	28	0.0097	27	0.0094
				735.25	**0.0272**		**0.0206**		**0.0199**
PM_{10}	asthma_adults	cough	7	46.65	0.0003	8	0.0004		0.0000
Nit	asthma_adults	cough	7	351.5	0.0025	8	0.0028		0.0000
Sul	asthma_adults	cough	7	358.2	0.0025	8	0.0029		0.0000
				756.35	**0.0053**		**0.0061**		**0.0000**
PM_{10}	asthma_adults	Lower resp. symptoms	7,5	16.87	0.0001	8	0.0001	44	0.0007
Nit	asthma_adults	Lower resp. symptoms	7,5	127.1	0.0010	8	0.0011	44	0.0056
Sul	asthma_adults	Lower resp. symptoms	7,5	129.5	0.0010	8	0.0011	44	0.0057
				273.47	**0.0021**		**0.0023**		**0.0120**
PM_{10}	asthma_children	Bronchodilator usage	37	9.084	0.0003	28	0.0003	27	0.0002
Nit	asthma_children	Bronchodilator usage	37	68.45	0.0025	28	0.0019	27	0.0018
Sul	asthma_children	Bronchodilator usage	37	69.76	0.0026	28	0.0020	27	0.0019
				147.294	**0.0054**		**0.0041**		**0.0040**
PM_{10}	asthma_children	cough	7	15.64	0.0001	8	0.0001		0.0000
Nit	asthma_children	cough	7	117.9	0.0008	8	0.0009		0.0000
Sul	asthma_children	cough	7	120.1	0.0008	8	0.0010		0.0000
				253.64	**0.0018**		**0.0020**		**0.0000**

			EcoSense			EXMOD		TER	
		Morbidity	**Monetary value**	**Central impacts**	**Damages**	**Monetary value**	**Damages**	**Monetary Value**	**Damages**
Pollutant	**ReceptorGroup**	**Impact**	**ECU**		**mECU/ kWh**	**ECU**	**mECU/ kWh**	**ECU**	**mECU/ kWh**
PM_{10}	asthma_children	Lower resp. symptoms	7.5	12.06	0.0001	8	0.0001	44	0.0005
Nit	asthma_children	Lower resp. symptoms	7.5	90.88	0.0007	8	0.0008	44	0.0040
Sul	asthma_children	Lower resp. symptoms	7.5	92.6	0.0007	8	0.0008	44	0.0041
				195.54	**0.0015**		**0.0016**		**0.0086**
Nit	children	chronic cough	225	52.23	0.0118	225	0.0118	59	0.0031
PM_{10}	children	chronic cough	225	6.932	0.0016	225	0.0016	59	0.0004
Sul	children	chronic cough	225	53.33	0.0120	225	0.0120	59	0.0031
				112.492	**0.0253**		**0.0253**		**0.0066**
Nit	children	case of chr. bronchitis	225	40.63	0.0091	225	0.0091	343	0.0139
PM_{10}	children	case of chr. bronchitis	225	5.392	0.0012	225	0.0012	343	0.0018
Sul	children	case of chr. bronchitis	225	41.48	0.0093	225	0.0093	343	0.0142
				87.502	**0.0197**		**0.0197**		**0.0300**
Cd	total	cancer	450000	1.48E-05	0.0000	169816	0.0000		
Cr	total	cancer	450000	0.001061	0.0005	169816	0.0002		
As	total	cancer	450000	2.41E-06	0.0000	169816	0.0000		
Ni	total	cancer	450000	9.64E-05	0.0000	169816	0.0000		
				1.17E-03	**0.0005**		**0.0002**		
PM_{10}	total	resp. hosp. admission	7870	0.02888	0.0002	11654	0.0003		
Nit	total	resp. hosp. admission	7870	0.2176	0.0017	11654	0.0025		
Sul	total	resp. hosp. admission	7870	0.2224	0.0018	11654	0.0026		
				0.46888	**0.0037**		**0.0055**		

			EcoSense			EXMOD		TER	
		Morbidity	Monetary value	Central impacts	Damages	Monetary value	Damages	Monetary Value	Damages
Pollutant	**ReceptorGroup**	**Impact**	**ECU**		**mECU/kWh**	**ECU**	**mECU/kWh**	**ECU**	**mECU/kWh**
PM_{10}	total	ERV for COPD	223	0.1005	0.0000	441	0.0000		0
Nit	total	ERV for COPD	223	0.757	0.0002	441	0.0003		0
Sul	total	ERV for COPD	223	0.7729	0.0002	441	0.0003		0
				1.6304	**0.0004**		**0.0007**		**0**
PM_{10}	total	ERV for asthma	223	0.09	0.0000	441	0.0000		0
Nit	total	ERV for asthma	223	0.6782	0.0002	441	0.0003		0
Sul	total	ERV for asthma	223	0.6924	0.0002	441	0.0003		0
				1.4606	**0.0003**		**0.0006**		**0**
PM_{10}	total	hosp. visits child. croup	223	0.406	0.0001	441	0.0002		0
Nit	total	hosp. visits child. croup	223	3.06	0.0007	441	0.0014		0
Sul	total	hosp. visits child. croup	223	3.124	0.0007	441	0.0014		0
				6.59	**0.0015**		**0.0029**		**0**
PM_{10}	total	cerebrov. hosp. adm	7870	0.07032	0.0006	11654	0.0008		0
Nit	total	cerebrov. hosp. adm	7870	0.5299	0.0042	11654	0.0062		0
Sul	total	cerebrov. hosp. adm	7870	0.541	0.0043	11654	0.0063		0
				1.14122	**0.0090**		**0.0133**		**0**
Hg	total	Exposed Persons > thresh.	155000	0	0.0000	705	0.0000		0
Ni	total	Exposed Persons > thresh.	155000	0	0.0000	705	0.0000		0
					0.0000		**0.0000**		**0**
Total Morbidity				11590.95	**1.0025**		**1.3726**		**0.3139**

			EcoSense			EXMOD		TER	
		Mortality	**Monetary value**	**Central impacts**	**Damages**	**Monetary value**	**Damages**	**Monetary Value**	**Damages**
Pollutant	**ReceptorGroup**	**Impact**	**ECU**		**mECU/ kWh**	**ECU**	**mECU/ kWh**	**ECU**	**mECU/ kWh**
PM_{10}	adults	Chronic mortality	3100000	0.5726	1.7751	2747027	1.5729		0
nit	adults	Chronic mortality	3100000	4.30E+00	13.3300	2747027	11.8122		0
sul	adults	Chronic mortality	3100000	4.40E+00	13.6400	2747027	12.0869		0
		Total		9.27E+00	28.7451		25.4721		0
PM_{10}	total	Acute mortality	3100000	0.05526	0.1713	2747027	0.1518	2815364	0.1556
Nit	total	Acute mortality	3100000	0.4164	1.2908	2747027	1.1439		
so2	total	Acute mortality	3100000	1.198	3.7138	2747027	3.2909		
Sul	total	Acute mortality	3100000	0.4308	1.3355	2747027	1.1834		
		Total			**6.5114**		**5.7700**		**0.1556**
	Total (total chronic + acute SO_2)				**32.4589**		**28.7630**		**0.1556**

Table 0.2 Impacts and damages calculated in EXMOD, compared to damages using EcoSense monetary values

					EXMOD		EcoSense	
		Central impacts	**Monetary value $**	**Damages in mills/kWh**	**Monetary value ECU**	**Damages in mECU/kWh**	**Monetary value ECU**	**Damages in mECU/kWh**
NO_x	Asthma attack	1233	34	1.2330	28	1.0264		
PM_{10}	Asthma attack	77	34	0.0770	28	0.0641		
SO_2	Asthma attack	20	34	0.0200	28	0.0166		
				1.3300		**1.1071**		
NO_x	Children, acute bronchitis	12.06	270	0.0958	225	0.0797		
PM_{10}	Children, acute bronchitis	6.64	270	0.0527	225	0.0439		
SO_2	Children, acute bronchitis	1.73	270	0.0137	225	0.0114		
				0.1622		**0.1351**		
NO_x	case of chr. bronchitis	1.738	210000	10.7347	174811	8.9359	105000	5.3674
PM_{10}	case of chr. bronchitis	0.957	210000	5.9109	174811	4.9204	105000	2.9554
SO_2	case of chr. bronchitis	0.25	210000	1.5441	174811	1.2854	105000	0.7721
				18.1897		**15.1417**		**9.0949**
NO_x	Emergency room visit (ERV)	9.94	530	0.1549	441	0.1290	223	0.0652
PM_{10}	Emergency room visit (ERV)	5.48	530	0.0854	441	0.0711	223	0.0359
SO_2	Emergency room visit (ERV)	1.43	530	0.0223	441	0.0186	223	0.0094
				0.2627		**0.2186**		**0.1105**

		Central impacts	Monetary value $	Damages in mills/kWh	EXMOD Monetary value ECU	EXMOD Damages in mECU/kWh	EcoSense Monetary value ECU	EcoSense Damages in mECU/kWh
NO_x	resp. symptoms days	15820	10	4.6529	8	3.8733	7.5	3.4897
PM_{10}	resp. symptoms days	2890	10	0.8500	8	0.7076	7.5	0.6375
SO_2	resp. symptoms days	750	10	0.2206	8	0.1836	7.5	0.1654
				5.7235		**4.7645**		**4.2926**
NO_x	resp. hosp. admission	2.135	14000	0.8791	11654	0.7318	7870	0.4942
PM_{10}	resp. hosp. admission	0.294	14000	0.1211	11654	0.1008	7870	0.0681
SO_2	resp. hosp. admission	0.076	14000	0.0313	11654	0.0261	7870	0.0176
				1.0315		**0.8586**		**0.5798**
NO_x	Restr. activity days	2030	70	4.1794	58	3.4791	75	4.4779
PM10	Restr. activity days	1118	70	2.3018	58	1.9161	75	2.4662
SO2	Restr. activity days	292	70	0.6012	58	0.5004	75	0.6441
				7.0824		**5.8956**		**7.5882**
	Radiation	0.02463	847	0.0006	705	0.0005		0.0000
				0.0006		0.0005		**0.0000**
Toxics	Mortality,	0.000521	3300000	0.0506	2747027	0.0421		0.0000
Toxics	Survivable	0.000542	204000	0.0033	169816	0.0027		0.0000
				0.0538		**0.0448**		**0.0000**

					EXMOD		EcoSense	
		Central impacts	Monetary value $	Damages in mills/kWh	Monetary value ECU	Damages in mECU/kWh	Monetary value ECU	Damages in mECU/kWh
NO_x	Mortality over 65	0.377	3000000	33.2647	2497297	27.6906	3100000	34.3735
PM_{10}	Mortality over 65	0.2139	3000000	18.8735	2497297	15.7109	3100000	19.5026
SO_2	Mortality over 65	0.0764	3000000	6.7412	2497297	5.6116	3100000	6.9659
				58.8794		**49.0131**		**60.8421**
NO_x	Mortality under 65	0.0336	4000000	3.9529	3329730	3.2906	3100000	3.0635
PM_{10}	Mortality under 65	0.01845	4000000	2.1706	3329730	1.8069	3100000	1.6822
SO_2	Mortality under 65	0.00453	4000000	0.5329	3329730	0.4436	3100000	0.4130
				6.6565		**5.5411**		**5.1588**
	Mortality total			**65.5359**		**54.5542**		**66.0008**

Table 0.3 Impacts and damages calculated in the TER study, rural scenario

Rural scenario Health		% health	Price/t $1993	$/MWh	Damage in $1993	Damage in EUR1995	Impacts /TWh	1995$ /MWh	1995EUR /MWh
Mortality								**0.033**	**0.025**
	PM	66.1	633	0.0320	3600000	2815364	0.01		
Morbidity								**0.020**	**0.015**
- Bronchitis	PM	0.3	633	0.0001	148	116	0.98	0.000	0.000
- Chronic cough	PM	8.6	633	0.0042	76	59	54.80	0.004	0.003
- Emphysema, etc.	PM	24	633	0.0116	8900	6960	1.31	0.012	0.009
- Cough days	PM	1	633	0.0005	76	59	6.37	0.001	0.000
- Chest discomfort	SO_2	100	3	0.0028	35	27	79.29	0.003	0.002
- Eye irritation	NO_x	100	15.5	0.0154	15	12	1028.17	0.016	0.012
- Lower respiratory	NO_x (O3)	-56	15	-0.0084	56	44	-149.25	-0.009	-0.007
- Upper respiratory	NO_x (O3)	-11	15	-0.0016	19	15	-86.41	-0.002	-0.001
- Chronic astma	NO_x (O3)	-33	15	-0.0049	439	343	-11.22	-0.005	-0.004
Agriculture									
	SO_2	100	6	0.0056				**0.017**	**0.013**
	NO_x	100	11	0.0109					
Miscellaenous									
Soiling	PM	100	16.5	0.0013				**0.010**	**0.008**
Visibility	PM	100	18.5	0.0014					
Materials	SO_2	100	8	0.0074					
							Total	**0.081**	**0.061**

Table 0.4 Impacts and damages calculated in the TER study, metropolitan scenario

Metropolitan scenario									
Health		% health	Price/t \$1993	\$/MWh	Damage in \$1993	Damage in EUR1995	Impacts /TWh	1995\$ /MWh	1995EUR /MWh
Mortality								**0.106**	**0.079**
	PM	61.6	2155	0.10155222	3600000	2815364	0.03		
Morbidity								**0.199**	**0.150**
- Bronchitis	PM	0.3	2155	0.00049457	148	116	3.34	0.001	0.000
- Chronic cough	PM	9.7	2155	0.01599118	76	59	210.41	0.017	0.013
- Emphysema, etc.	PM	27.4	2155	0.04517096	8900	6960	5.08	0.047	0.035
- Cough days	PM	1	2155	0.00164858	76	59	21.69	0.002	0.001
- Chest discomfort	SO_2	100	17.5	0.0161875	35	27	462.50	0.017	0.013
- Eye irritation	NO_x	100	54	0.05373	15	12	3582.00	0.056	0.042
- Lower respiratory	NO_x (O3)	89	58.5	0.05180468	56	44	925.08	0.054	0.041
- Upper respiratory	NO_x (O3)	11	58.5	0.00640283	19	15	336.99	0.007	0.005
- Chronic astma	NO_x (O3)	0	58.5	0	439	343	0.00	0.000	0.000
Agriculture									
	SO_2	100	23	0.021275				**0.050**	**0.037**
	NO_x	100	26.5	0.0263675					
Miscellaenous									
Soiling	PM	100	67	0.0051255				**0.043**	**0.032**
Visibility	PM	100	75	0.0057375					
Materials	SO_2	100	33	0.030525					
							Total	**0.397**	**0.299**

Table 0.5 Impacts and damages calculated in the TER study, urban scenario

Urban scenario								1995	
Health		% health	Price/t $1993	$/MWh	Damage in $1993	Damage in EUR1995	Impacts /TWh	1995$ /MWh	1995EUR /MWh
Mortality								**0.229**	**0.172**
	PM	59.9	4798	0.2199	3,600,000	2,815,364	0.06		
Morbidity								**0.469**	**0.352**
- Bronchitis	PM	0.3	4798	0.0011	148	116	7.44	0.001	0.001
- Chronic cough	PM	10	4798	0.0367	76	59	482.96	0.038	0.029
- Emphysema, etc.	PM	28.7	4798	0.1053	8900	6960	11.84	0.110	0.082
- Cough days	PM	1.1	4798	0.0040	76	59	53.13	0.004	0.003
- Chest discomfort	SO_2	100	30.5	0.0282	35	27	806.07	0.029	0.022
- Eye irritation	NO_x	100	130	0.1294	15	12	8623.33	0.135	0.101
- Lower respiratory	NO_x (O3)	85	146.5	0.1239	56	44	2212.54	0.129	0.097
- Upper respiratory	NO_x (O3)	10	146.5	0.0146	19	15	767.20	0.015	0.011
- Chronic astma	NO_x (O3)	5	146.5	0.0073	439	343	16.60	0.008	0.006
				0.4505			12981.10		
Agriculture									
	SO_2	100	21	0.0194				**0.202**	**0.152**
	NO_x	100	176	0.1751					
Miscellaenous									
Soiling	PM	100	158	0.0121				**0.114**	**0.085**
Visibility	PM	100	174.5	0.0133					
Materials	SO_2	100	90.5	0.0837					
							Total	**1.013**	**0.762**

Table 0.6 Impacts and damages calculated in TER, compared to damages using EcoSense monetary values

			TER			EcoSense	
Health		% health	Monetary value EUR1995	Impacts/TWh	EUR/MWh	Monetary value EUR1995	EUR/MWh
Mortality							
	PM	59.9	2,815,364.3	0	0.1719	3,100,000	0.1893
Morbidity					0.3523		1.4089
- Bronchitis	PM	0.3	115.7	7	0.0009	225.0	0.0017
- Chronic cough	PM	10	59.4	483	0.0287	225.0	0.1087
- Emphysema, etc.	PM	28.7	6960.2	12	0.0824	105,000	1.2428
- Cough days	PM	1.1	59.4	53	0.0032	75.0	0.0040
- Chest discomfort	SO_2	100	27.4	806	0.0221	37.0	0.0298
- Eye irritation	NO_x	100	11.7	8623	0.1012	0.0	0.0000
- Lower respiratory	NO_x (O3)	85	43.8	2213	0.0969	7.5	0.0166
- Upper respiratory	NO_x (O3)	10	14.9	767	0.0114	7.0	0.0054
- Chronic asthma	NO_x (O3)	5	343.3	17	0.0057	0.0	0.0000

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Differences in methodologies used for externality assessment – Why are the numbers different?

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Abstract (max. 2000 characters)

During the last few years, externalities related to power production technologies have been calculated making use of different methodologies. The external costs may turn out to be very different for the same fuel cycle depending on the methodology that has been used to assess the externalities.

The report gives a review of different valuation issues, which are used in different externality studies and focuses on why the numbers often are different for the same fuel cycle, using different methodologies for assessment of the externalities. The review of externality valuation focuses in this report on the assessment of environmental externalities. Importance has been attached to health effects, as these are the dominating effects in the external costs. Other effects are only mentioned on a superior level.

The report points out different parameters, which are important to consider when externalities estimated for the same fuel cycle in different studies are compared. 8 studies have been chosen for further analysis and comparison in order to show the variation in external costs. The comparison shows the importance of possessing knowledge of which kind of methodologies have been used, which impacts are included etc. to explain why the numbers vary so much in different studies for the same fuel cycle.

As an example a comparison of the impacts and damage costs related to air emissions has been made for three studies using different methodologies. The external costs are estimated for the same reference plant using the dispersion models, dose-response functions, impacts and monetary values from the three studies. The estimates from the three studies are compared two and two, and a more detailed analysis is performed in relation to human health, which is the dominating impact in all externality studies.

Descriptors INIS/EDB

AIR POLLUTION; COMPARATIVE EVALUATIONS; COST ESTIMATION; ECONOMIC ANALYSIS; ENVIRONMENTAL IMPACTS; FUEL CYCLE; HEALTH HAZARDS; POWER SYSTEMS

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